SEISMIC PERFORMANCE OF MULTISTOREY REINFORCED CONCRETE BUILDINGS

BY PUSHOVER ANALYSIS

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In

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By

Yaar Muhammad

(111CE0555)

UNDER THE GUIDANCE OF

PROF. U.K Mishra

Department of Civil Engineering

National Institute of Technology, Rourkela

ODISHA-769008, INDIA

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NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA, ORISSA -769008, INDIA

CERTIFICATE

This is to certify that this thesis entitled "**SEISMIC PERFORMANCE OF MULTISTOREY REINFORCED CONCRETE BUILDINGS BY PUSHOVER ANALYSIS** "submitted by **Yaar Muhammad (111CE0555)** in partial fulfillment for the award of the degree of Bachelor of Technology in Civil Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other university/institute for the award of any degree or diploma.

Date: 11-May-2015

Prof. U.K Mishra
(Project Supervisor)
Department of Civil Engineering,
National Institute of Technology Rourkela,
Rourkela-769008, Odisha, Ind

ABSTRACT

The buildings are constructed mostly based on the usual standard codes considering the gravity loads consisting of the self-weight of the structure and the live load. These structures are experiencing low magnitude loads in their design life that leads only to the elastic range response, however, strong loads such as a sudden earthquake will lead the structure beyond its elastic limit. The performance of Reinforced Concrete structures will be nonlinear under seismic loads so the nonlinear behavior of reinforced buildings will be defined by the formation of plastic hinges and loss of considerable stiffness. In this case we need a method to evaluate the performance level of the structure in the plastic range, hence we used pushover analysis to evaluate the response of the structure to the lateral loads

For the explanation above the best example can be the devastating earthquake of Nepal (25th April 2015) which has affected many buildings constructed based on traditional design codes. So it’s important to use deformation based design to avoid or at least develop the ductile behavior for structure; this will avoid the collapse of the building and will surely ensure life safety.

In present study pushover analysis is carried out on G+4, G+11 and G+21 Building situated in New Delhi (Zone IV) according to IS 1893:2002 classification of seismic zones in India. Pushover analysis was performed in SAP2000 after it was designed for gravity loads in STAAD Pro based on IS-456-2000. The pushover curve, capacity spectrum, demand spectrum and Performance point of the building was found from the results of SAP2000 and hence it was concluded that the building response is highly dependent on the materials used in the design. Mostly the failure was noticed in the columns of ground story of the buildings. After using increased amount of reinforcement in the ground story the buildings have reached life safety performance level.

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NOTATION AND ABBREVIATION

E	Young's Modulus
ρ	Density
α	Temperature Coefficient
M25	Grade of Concrete
fy	Yield stress of steel
Z	Zone factor
I	Importance factor
RF	Response reduction factor
M3	Flexural moment
P-M2-M3	Axial force with biaxial moment
RC	Reinforced Concrete
IS:	Indian Standards
DL:	Dead Load
LL:	Live Load
Z:	Zone Factor

CHAPTER 1

1.1 Performance Based Design

The standard building codes define the significant design requirements to ensure the safety of residents in a sudden ground shaking events. We usually witness the natural disaster effects on buildings even designed based on building codes. Considering the devastating Nepal earthquake of 25^{th} April 2015, many buildings satisfying minimum code requirements were also affected by this devastating event. Therefore it is important to analysis the building performance before physically constructing it. The performance based design gives you the choice to check the story drift, displacement at the roof level and the capacity before the building fails for certain ground motions. The performance based design ensures the safety for the Design Basis Earthquake (DBE) and Collapse prevention for Maximum Considered Earthquake (MCE).

The performance of building means how well it satisfies the needs of its users. Acceptable performance levels of damage indicates the uninterrupted functionality of the buildings structural elements as well as non-structural elements. The safety of non-structural elements can be ensured through performance based design with increase in cost of the construction. Consequently, performance-based design is the procedure or approach used by design specialists to construct buildings that possess functionality and the continued availability of services.

The performance based design methodology is not going to be the immediate substitute for design to the traditional code methods. Rather, it can be viewed as an opportunity to enhance and adapt the design to match the objectives. It will only help in enhancing the design criteria in determining the deformation based response.

The important points of performance based design:

I. Performance based design considers deformation and forced based design considers strength. However for seismic performance deformation is more important.

II. The Design is done by using a target displacement

III. There is no need of using force reduction factor

IV. The non-linear behavior of the structure is considered which gives more strength.

V. Displacement based design can indicate the potential damage in any weak member of the structure, hence it can be retrofitted.

VI. Displacement based design is applied to both existing and new structures.

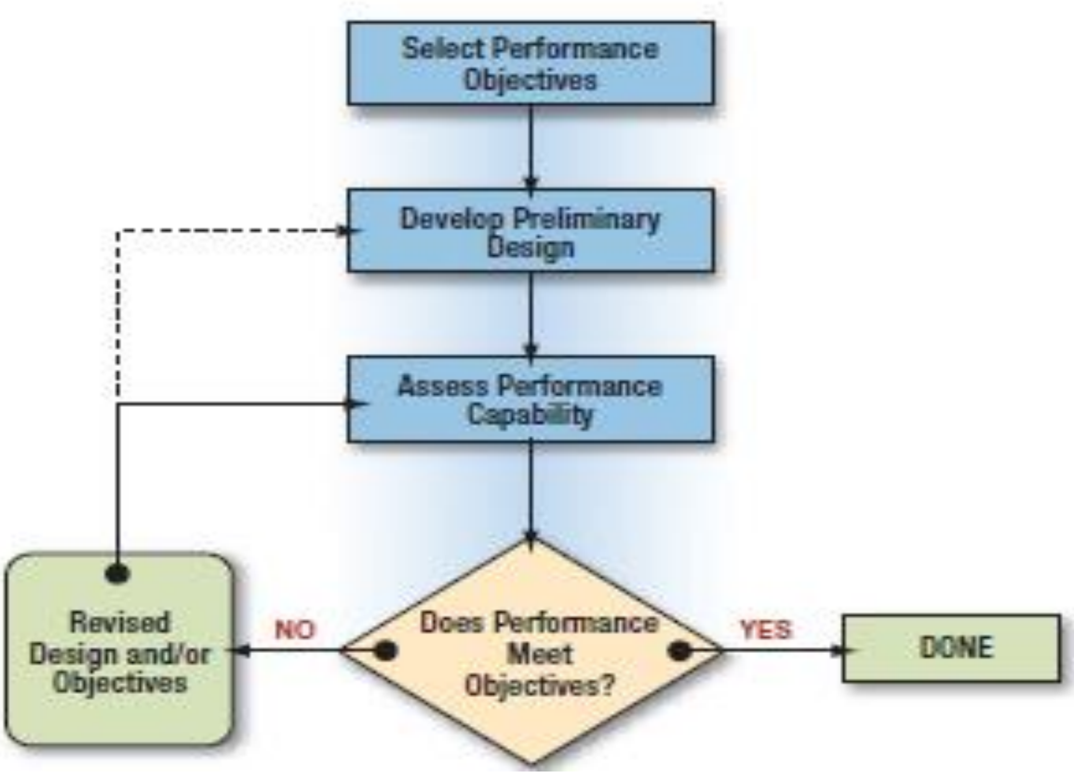


Figure 1.1: Flow Diagram showing Performance Based Design

1.2 Building Performance Levels

For performance-based seismic design, the performance levels Described ASCE 41, Seismic Rehabilitation of Existing Building (2007), for both structural and nonstructural systems are the most Widely-recognized characterizations. These performance levels are described below:

1. **Operational Building Performance Level**:

   Structures that accept this performance level are expected to have no damage to the structural and nonstructural elements. The building can normally operate without any interruptions but there should be little adjustments for power, water etc. Basically even the occupants are not required to vacant the building. This level of performance is considered as the most efficient level but this can't be achieved for each structure as it is not effective from the economic point of view.

2. **Immediate Occupancy Building Performance Level:**

   Structures that have this performance level "Immediate occupancy" are expected to have minimal damage to the structural component and only limited damage to the nonstructural elements. It is completely safe to reoccupy the building following an earthquake. But some nonstructural components maybe repaired especially fragile nonstructural elements maybe having damages.

   The risk to the occupants is very less at this level of performance. This level of performance is also not so much cost effective. The basic safety requirements as per code is the life safety.

Key characteristics of immediate occupancy:

I. The members nearly retain their strength and stiffness
II. No crushing of concrete
III. Hairline crack can be seen
IV. Up to 1% transient drift with negligible permanent drift
V. Minor cracking or spalling of plaster in brick walls
VI. Risk of life threatening injury is negligible
VII. Minor structural repairs may be necessary
VIII. Building can be reoccupied before the repairs

3. Life Safety Building Performance Level

Structures that have this performance level "Life Safety" are expected to have extensive damage to both the structural and nonstructural elements.

It should be noted that the occupants may not be able to reoccupy the building, repairs should be done before coming back to the building.

At this level there is slight increase in risk to the occupants in the buildings.

Life safety is considered as basic performance objective under Design basis earthquake as per the FEMA 356 code.

Key characteristics of Life safety performance level:

I. There is significant damage to the building
II. Extensive damage is observed in beams
III. There will be spalling of concrete cover in columns
IV. Transient drift will be about 2%, with 1% permanent drift
V. Extensive cracking and some crushing in brick walls
VI. Life threatening hazard is low
VII. Major structural repair can be done
VIII. Partial repair before reoccupying

4. Collapse Prevention Building Performance Level:

Structures that meet this level of performance may experience increased amount of risk to the life of occupants as the nonstructural elements failure, but the loss of life will be avoided as the building will only develop plastic hinges, basically it will develop deep cracks but the entire building wont collapse. The repair work will not be recommended, in most cases the building need to be demolished.

Key characteristics of Collapse prevention performance level:

I. Degradation of lateral load resisting system
II. The vertical load system supports gravity load without any margin of safety against collapse
III. Formation of hinges in the ductile elements
IV. About 4% permanent drift
V. Extensive cracking and dislodging of walls
VI. Significant risk of injury
VII. The building may not be repairable

1.3 Why Non-Linear pushover Analysis?

Pushover analysis is a performance based design which is recommended by Euro code and FEMA 273 and FEMA 356. This method considers the nonlinear behavior of the structure which increases the load taking capacity of the building. It also focuses on ductility of the structure by providing plastic hinges. Pushover analysis is applicable to new and existing structures which can be a good method for retrofitting of structures after its design life is over. It considers target displacement and defining objectives whenever the performance meet the objectives then the damage at that performance level is acceptable.

Pushover analysis determine the following characteristics of structures:

I. Load Demand of the structures.
II. Knowing the loss in strength of individual elements and its effects on the structure overall.
III. Determining the critical sections where the deformations are high and need to be focused in the design process.
IV. Determining the loss in stiffness, and its dynamic characteristics in the nonlinear portion
V. Determining the best load path in applying to the structure for best seismic response.

1.4 Objective of the present study

The objective of the present study is to design a 5, 12 and 22 story buildings in STAAD pro as per IS-456-2000 for gravity loads and then perform pushover analysis in SAP2000 to get the seismic response of the structure. The main objective is to check whether the building designed by standard codes are safe under earthquake loads. Basically seismic analysis is done to ensure life safety under Design Basis Earthquake (DBE) and collapse prevention under Maximum Considered Earthquake (MCE).

1.5 Methodology

1. Literature Review for understanding the concept
2. Identifying the building plan and material properties
3. Modelling the plan in STAAD Pro to design for gravity loads as per IS-456-2000
4. Importing the same model to SAP2000 to evaluate for performance based Design.
5. Develop plastic hinge properties to both ends of each beam and column section as per FEMA 356.
6. Analysis of the building using pushover
7. Results in terms of pushover curve (Base shear vs Displacement)

CHAPTER 2

2.1 General

Pushover analysis is a popular performance based design method, so there are many studies conducted using this method. Most of these studies assumed that the lateral force distribution was an inverted triangular distribution, according to recommendation of codes only flexural plastic hinges were considered. However in this study the dynamic characteristics of the structures are considered, for example while applying the pushover load case mode shapes were considered. It was also studied that mode shapes and the lateral distribution of base shear gives the same results.

The following are some studies in brief:

A.Kadid and A. Boumrkik (2008), Pushover analysis was conducted to assess the damage level of a building using Algerian Design code. The load was incrementally applied in the lateral directions. From the capacity or Pushover curve the target displacement at roof level was determined. The level of damage experienced by the structure at this target displacement is considered representative of the damage experienced by the building when subjected to design level ground motions. The seismic loads will result in plastic response of the structure, beyond its elastic limit. The response is dominated by ductile behavior of the structure in terms of plastic hinges. [1]

Abu Lego (2010) Site Response Spectra was used to study the response of buildings due to earthquake loading. . According to the Indian standard for Earthquake resistant design (IS: 1893), the seismic force or base shear depends on the zone factor (Z) and the average response acceleration coefficient (Sa/g) of the soil types at thirty meter depth with suitable modification depending upon the depth of foundation. In the present study an attempt has been made to generate response spectra using site specific soil parameters for some sites in Arunachal Pradesh and Meghalay in seismic zone V and the generated response spectra is used to analyze some structures using the design software STAAD Pro. [2]

Saptadip Sarkar (2010) by using STAAD Pro he studied the design of earthquake resistant RC buildings on sloping ground by changing the number of bays and floor heights. From the analysis results various graphs were drawn between the maximum axial force, maximum shear force, maximum bending moment, maximum tensile force and maximum compressive stress being developed for the frames on plane ground and sloping ground. From the studies the “Short column effects” were carefully studied. It was concluded that the software STAAD is a good tool in studying static linear behavior of the buildings.

Durgesh C. Rai (2005) He has developed guidelines for seismic evaluation and strengthening of buildings. The document was developed as part of project “Review of Building Codes and Preparation of Commentary and Handbooks” awarded to Indian Institute of Technology Kanpur by the Gujarat State Disaster Management Authority (GSDMA), Gandhinagar through World Bank finances. This document is particularly concerned with the seismic evaluation and strengthening of existing buildings and it is intended to be used as a guide.

Siamak Sattar and Abbie B. Liel quantified the effect of the presence and configuration of masonry infill walls on seismic collapse risk. Infill panels are modeled by two nonlinear strut elements, which have compressive strength only. Nonlinear models of the frame-wall system were subjected to incremental dynamic analysis in order to assess seismic performance. There was an increase observed in initial strength, stiffness, and energy dissipation of the infilled frame, when compared to the bare frame, even after the wall’s brittle failure modes. Dynamic analysis results indicated that fully-infilled frame had the lowest collapse risk and the bare frames were found to be the most vulnerable to earthquake-induced collapse. The better collapse performance of fully-infilled frames was associated with the larger strength and energy dissipation of the system, associated with the added walls.

2.2 Summary of Literature Review

Pushover analysis basically studies the inelastic response of structures under laterally applied loads of earthquake, properly selection of lateral load pattern and accurate interpretation of results are performed. It was studied that this method is simple and accurate enough to use. Only non-linear dynamic analysis is more accurate than pushover analysis; where non-linear dynamic analysis is time taking to perform.

So we can conclude that pushover analysis is the appropriate method to use for performance based design to get the response of the structures.

From the literature review we can conclude the followings points:

1. Pushover analysis is the best solution to determine the complex multi degree of freedom systems responses in terms of capacity and deformation demand.
2. Most of the research is done on 2D frames and steel buildings, the 3D analysis for irregular buildings is better to perform for determining the response of irregular buildings.
3. The conventional code-based method has many deficiencies according to neglecting higher mode contribution, stiffness degradation and the period elongation, but this method is the suitable one out there at the moment.
4. Among several modified method "Adaptive Pushover Analysis" (APA) proposed by Antoniou and Pinho in 2004 [7], seems to be more rational, since the others are complicated theoretically. Also they have protracted procedures.
5. Based on the study of the authors, 2007 the "interstorey drift-based scaling adaptive Pushover method" could be nominated as the most precise type of pushover analysis.

2.3 Seismic engineering in General

Seismic engineering is a branch of structural engineering its
It focuses on the following:

- To understand communication of structures with the ground motions.
- To predict the significances of possible earthquakes.
- To design, construct and maintain structures to perform at earthquake exposure up to the expectations and according to building codes.

The methodologies available so far for the evaluation of existing and new buildings can be divided into two categories:

1. Qualitative method
2. Analytical method.

Seismic analysis is a branch of structural analysis and is the determination of the response of the buildings under earthquake loadings. Seismic engineering especially the performance based design is very efficient in the regions where frequent quakes are happening. By using performance based design the structure can be retrofitted. The performance based design is the perfect methodology for retrofit program.
The methods of seismic response calculation are as follow:

I. Force method
II. Response Spectrum Analysis
III. Time history analysis
IV. Pushover analyis
V. Nonlinear Dynamic Analysis

In the present study pushover analysis is used for getting the response of 5, 12 and 22 story buildings.

2.4 Limitation of Pushover analysis

Pushover analysis a procedure with many advantages in comparison to the traditional elastic analysis. The accuracy of this method depends on the prediction of lateral load pattern, the target displacement, and the use of higher modes of vibrations. Target displacement is very significant in determining structure behavior. Properly estimation of this displacement will lead to accurate response of the structure. [7]

In this nonlinear procedure the target displacement for Multi degree of freedom system is also estimated in a similar procedure used for Single degree of freedom system. Most of the times in pushover analysis the elastic first mode of the structure is considered for determination of seismic responses. [7]

In this study the lateral forces calculated as per IS 1893 are applied to the structure in consideration of diaphragm action in the floors and determination of center of mass. Where the first mode shape was also used in determining the response, it was observed that both the load patterns are giving the same results.

CHAPTER 3 Structural Modelling

3.1 Overview

The whole chapter discusses about the properties of the materials used for the designing of the structure, the building plans and details and about the load applied to the structure. First the structure was modelled in STAAD Pro in 3D form and the gravity loads consist of Dead load of beams and columns, floors, brick infill and live load of 4 KN/m^2 were applied to the structure. Then the model was exported to SAP2000 for evaluation of its seismic response.

3.2 Material Properties

The materials used in the designing was M30 grade concrete and Fe415 steel reinforcements.

Concrete properties:

Young's Modulus(E)	21718500 KN/m^2
Poisons Ratio (nu)	0.17
Density	23.5616 KN/m^3
Thermal Coefficient(a)	10^{-5}
Critical Damping Ratio	0.05

Table 3.1 Concrete Properties

Steel Properties

Young's Modulus(E)	$2*10^5$ KN/m^2
Poisons Ratio (nu)	0.3
Density	76.8195 KN/m^3
Thermal Coefficient(a)	$1.2*10^{-5}$/c
Critical Damping Ratio	0.03

Table 3.2 Steel Properties

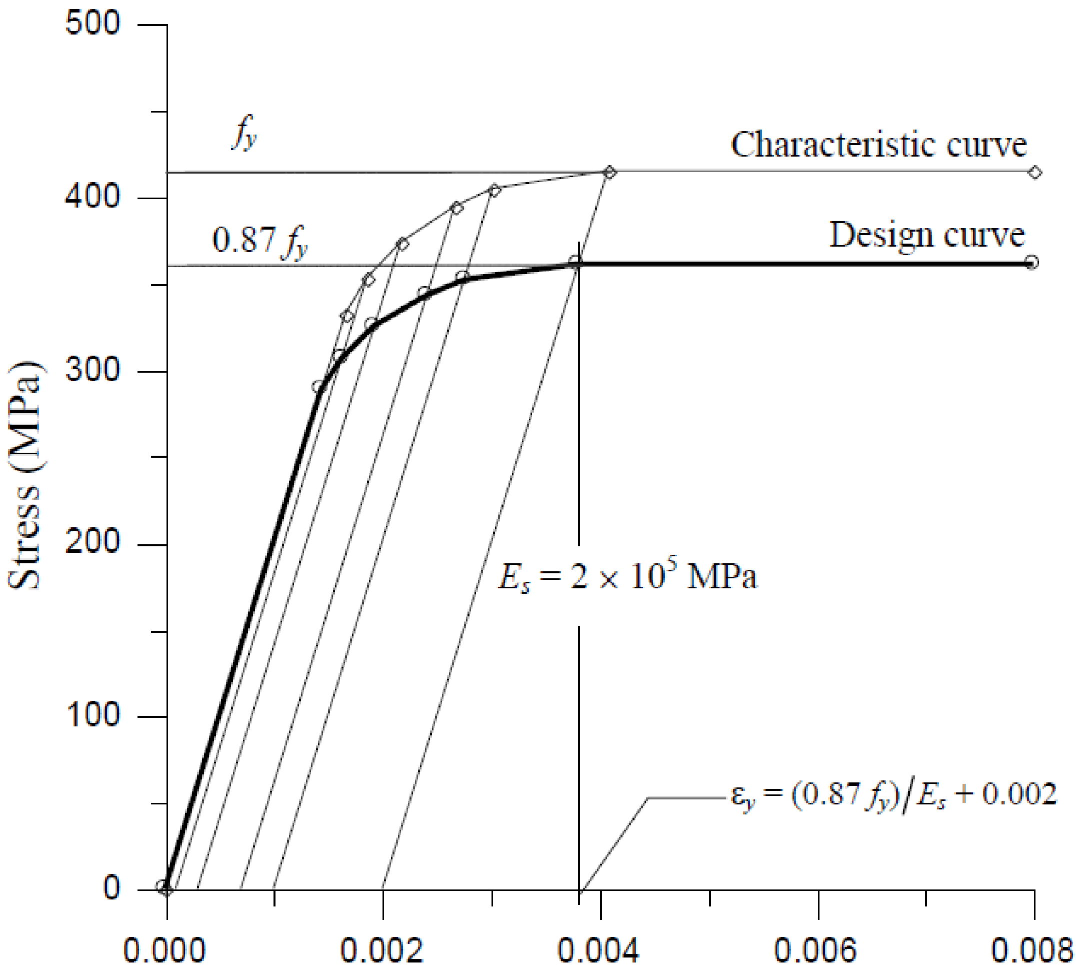


Figure 3.1 Stress-strain relationship for steel – IS 456-2000

3.3 Modelling

The Buildings are designed to resist Dead load, Live load and seismic load. As per IS-456-2000 various load combination were taken and the worst case was considered in the designing of the building. Dead load consists of Self weight, brick infill and floor load. Self-weight which indicates the load of beams and columns that are being calculated by STAAD Pro itself based on the dimensions applied. , considering slab thickness 130mm floor load was calculated based on unit weight of concrete to be 3.25KN/m^2 and brick infill load was taken as uniform force of 20 KN/m.

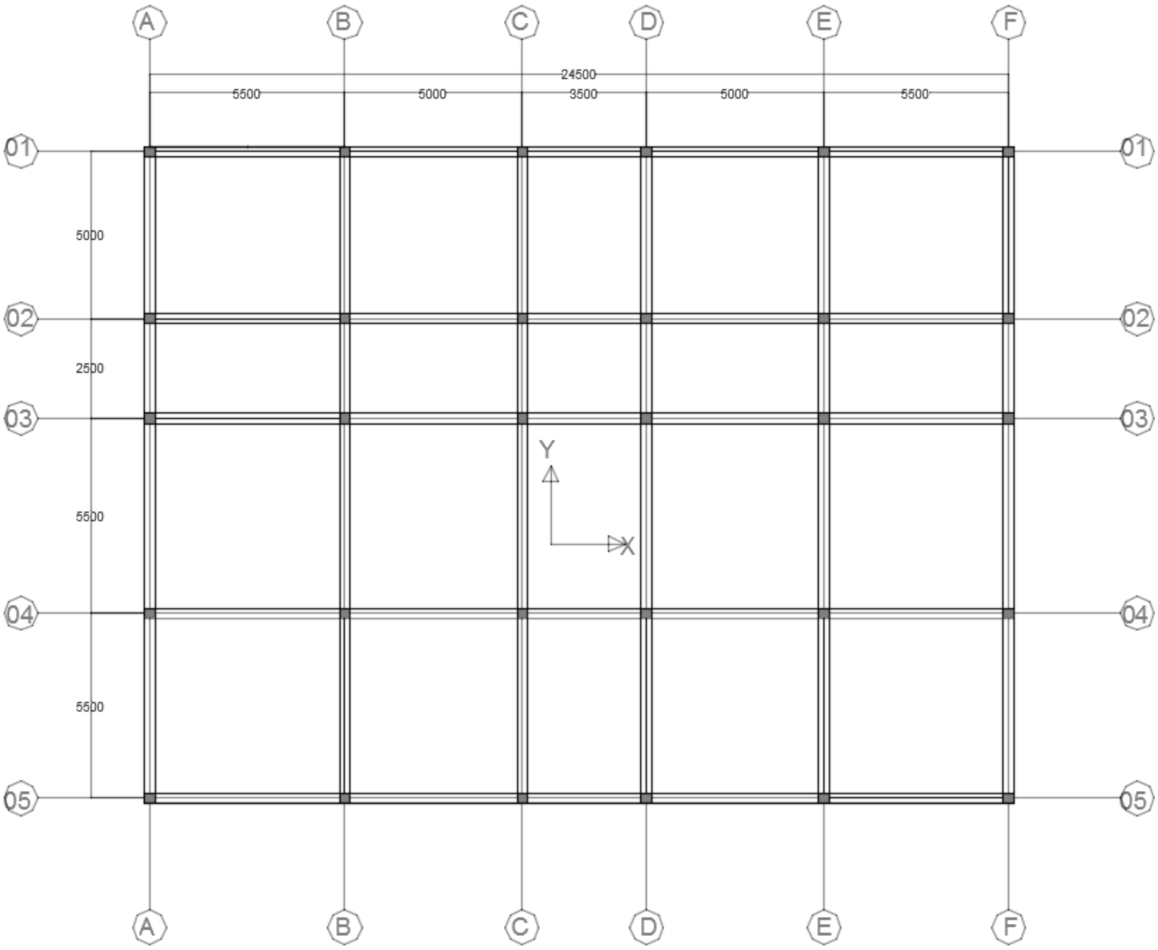


Figure 3.2 showing the plan the building

The building is 24.5n into 18.5m. Its area is 453.25m2

The beams dimensions are taken 300mmx450mm and for columns to be 450mmx450mm. However for 22 Story building these sections were not adequate and the ground columns collapsed after performing pushover analysis.

So for the 22 story building new dimensions of beams and columns were selected:

Beams: 600x800mm

Ground floor columns: 1000x1000mm

Other floors: 800x800mm

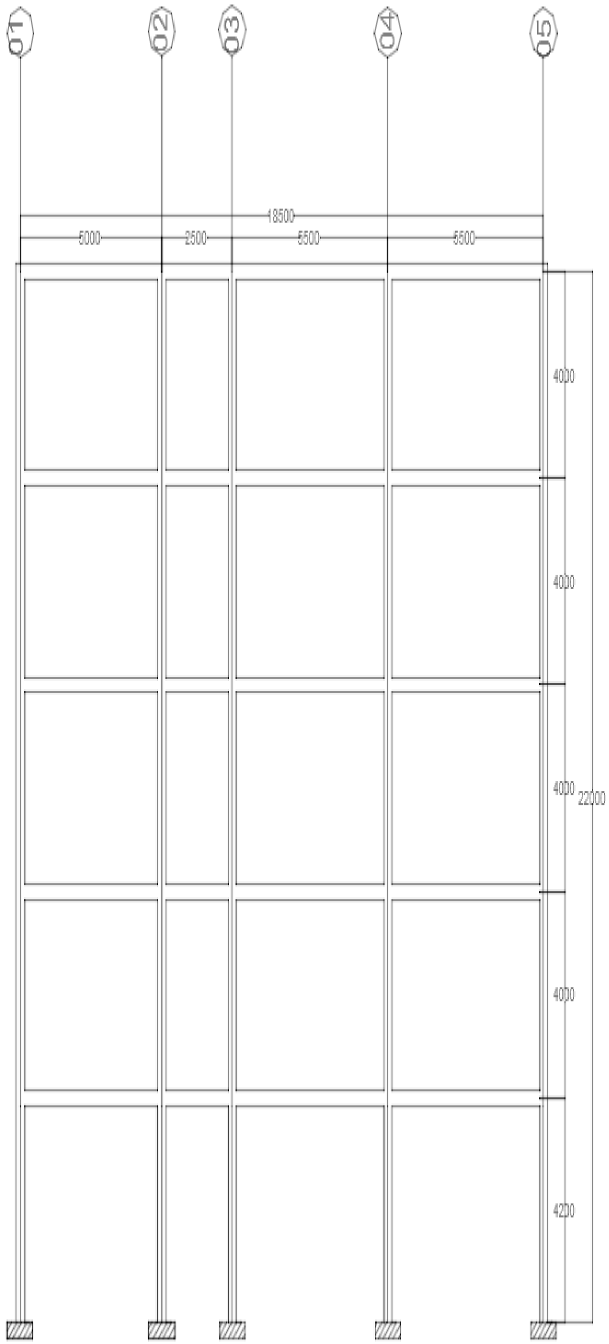


Figure 3.3 Section A-A of 5 Story Building

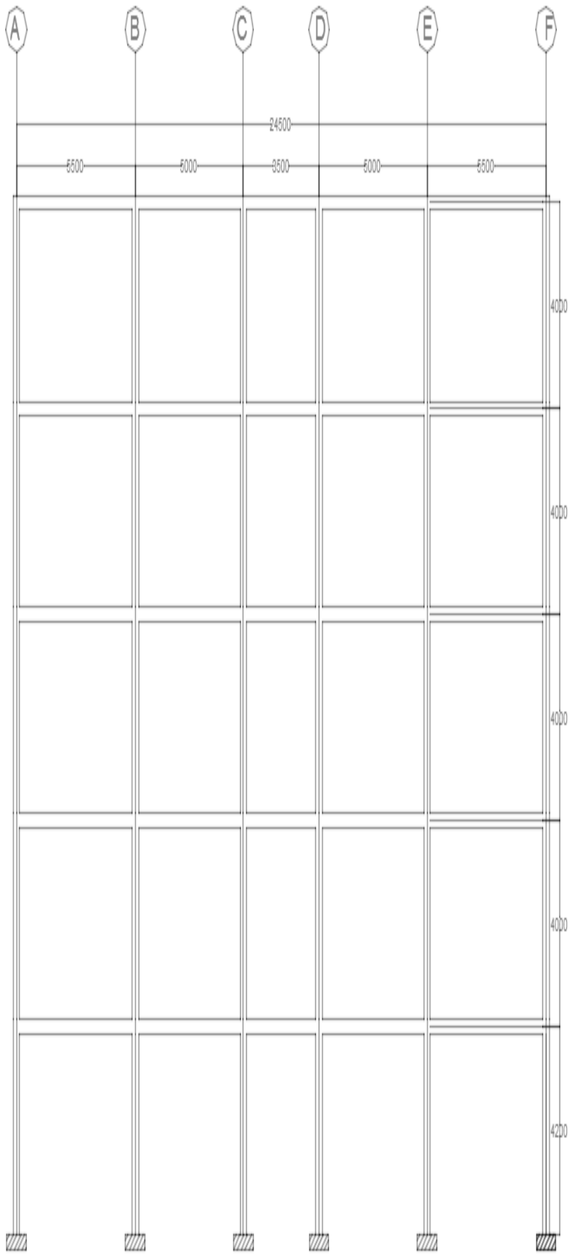
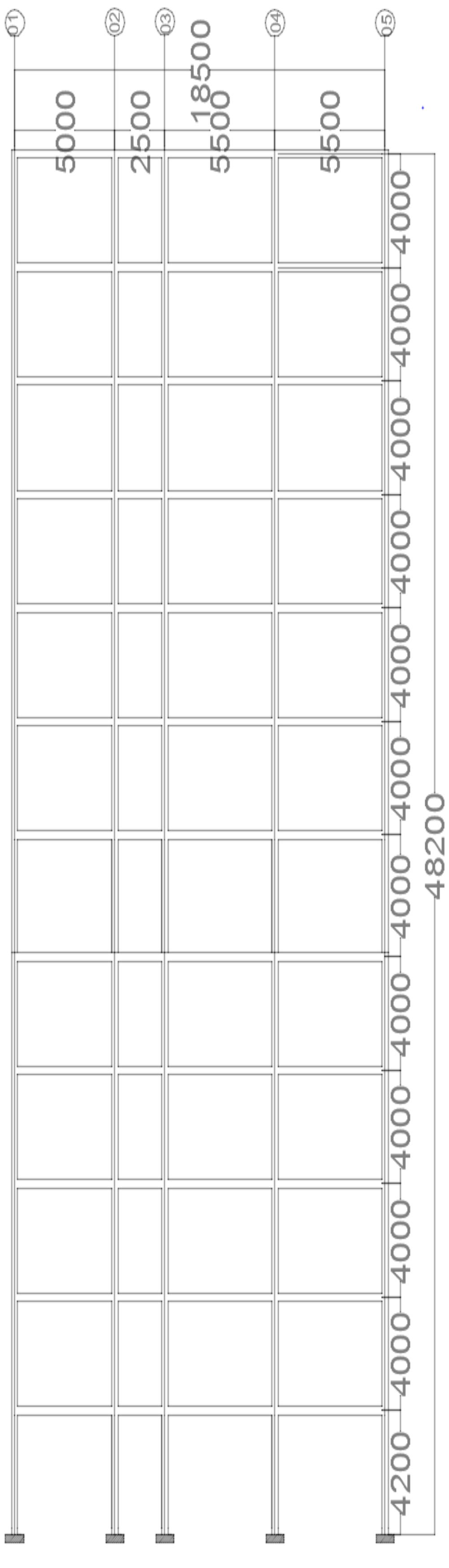


Figure 3.4 Section 1-1 of 5 Story Building



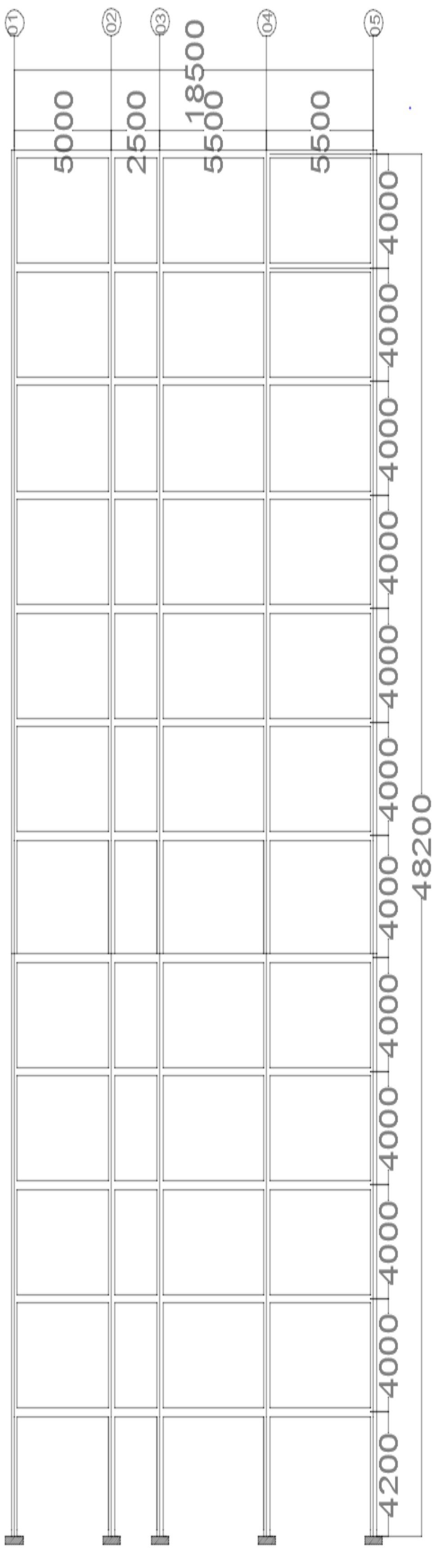


Figure 3.5 Section A-A of 12 Story Building **Figure 3.6 Section 1-1 of 12 Story Building**

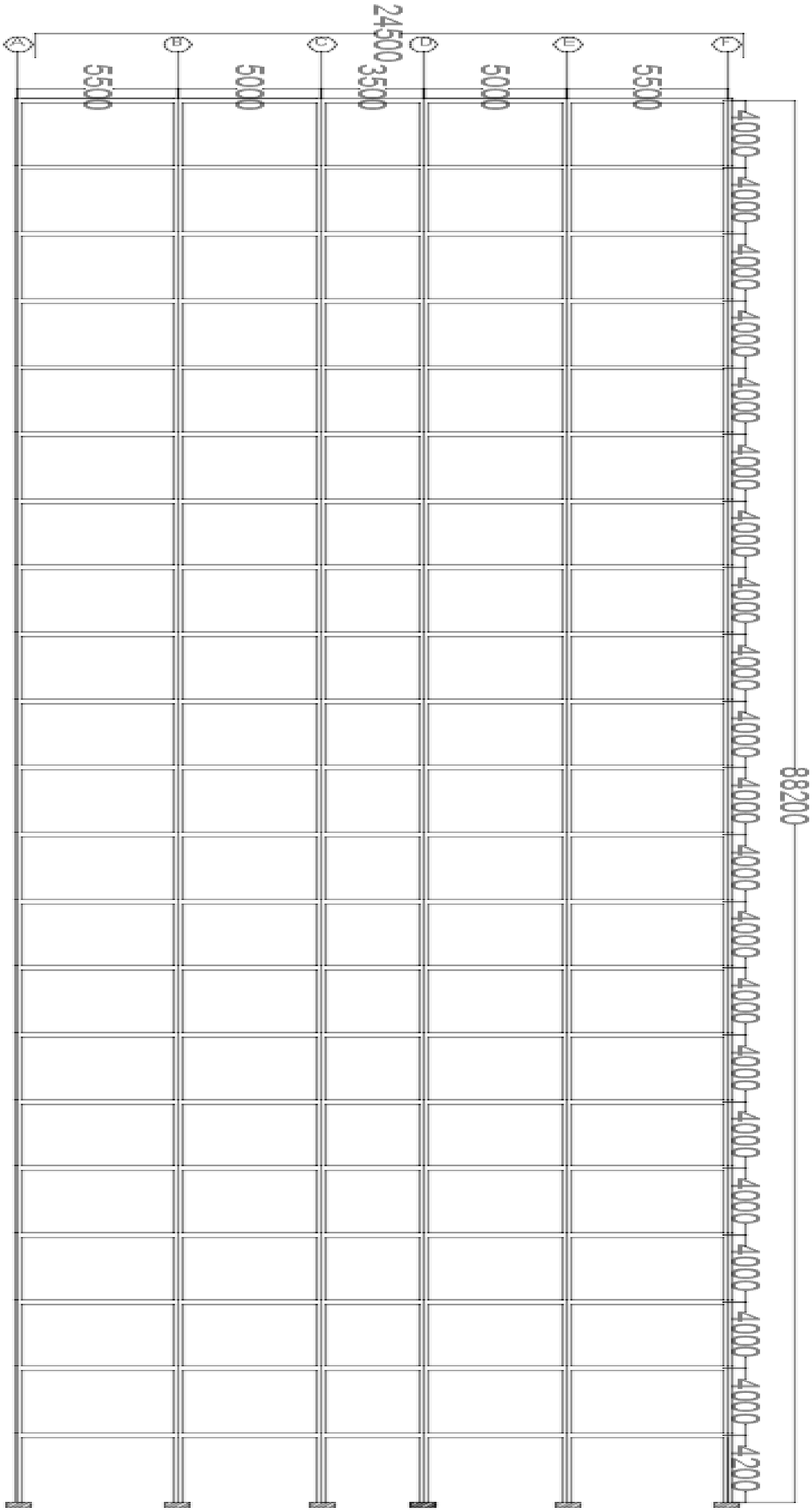


Figure 3.7 Section 1-1 of 22 Story Building

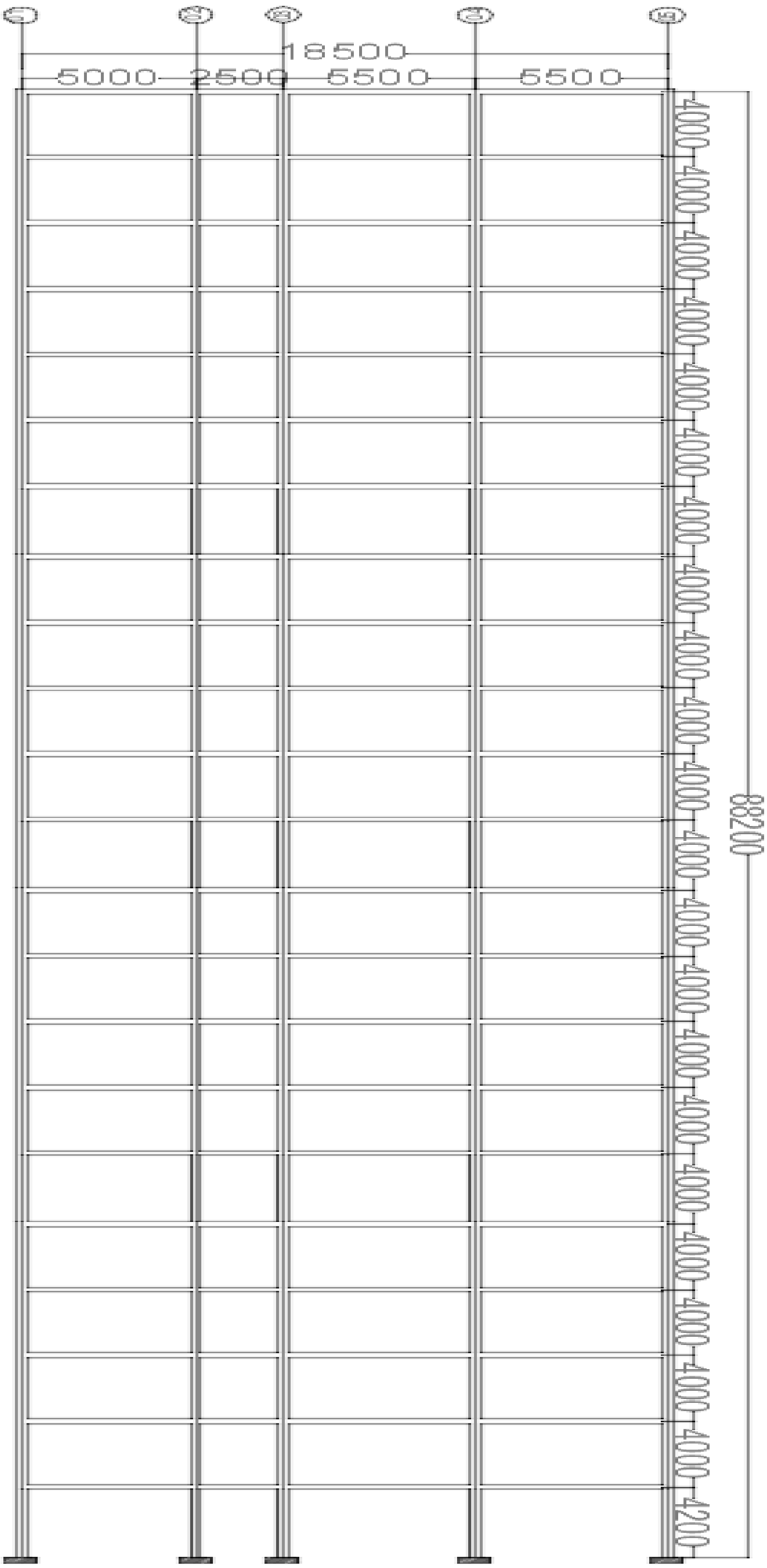


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Figure 3.8 Section A-A of 22 Story Building

3.4 Seismic Weight Calculation

As per IS 1893:2002 the following seismic parameters were used to calculate the seismic forces.

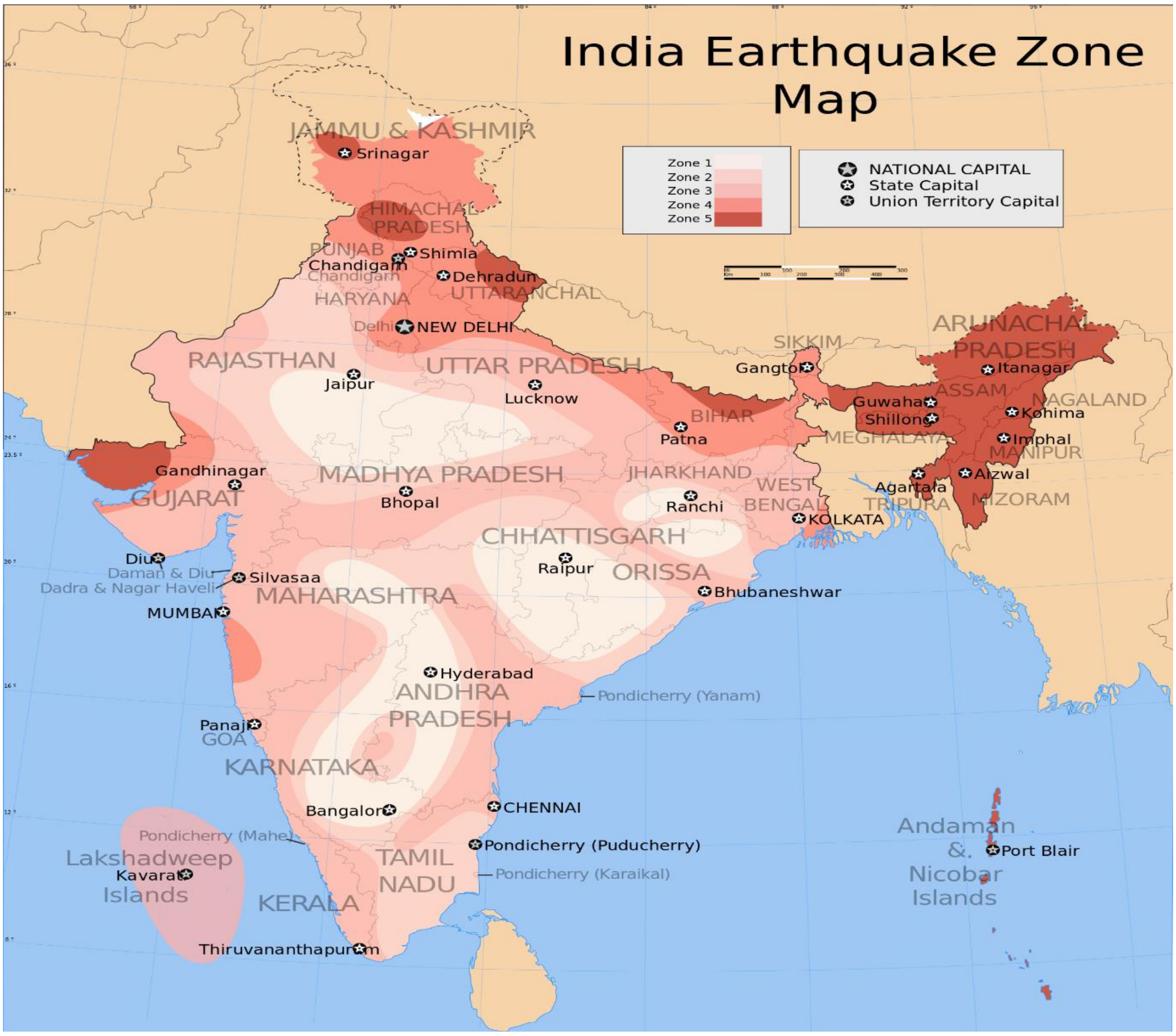


Figure 3.9 showing the India earthquake zone map

Zone Factor (Delhi) Z= 0.24 (Zone IV)

Importance Factor I= 1.0

Response reduction factor (RF) = 5 (Special Moment Resisting Frame)

Soil type= Medium Soil

Damping ratio = 0.05

$V_B = \frac{ZI}{2R}\frac{Sa}{g} x W$

V_B=Base shear

Z=Zone factor, for maximum considered earthquake (MCE)

Z/2 is used to reduce the MCE to Design basis Earthquake (DBE)

I=The Importance Factor depending upon the functional use of structures characterized by hazardous consequences of its failure

R=Response reduction factor depending on the perceived seismic damage performance of the structure

Sa/g is the average response acceleration coefficient

Table 3.3 Showing dimension and other details

Beams Size	300x450mm
Column size	450x450mm
Slab thickness	150mm
Concrete Grade	M25
Brick infill thickness	120mm
Brick masonry unit weight	20KN/m
Unit weight of RCC	25 KN/m^3
Live Load	4 KN/m^2

Seismic load Calculation for 5 story Building

Weight of typical floor=24.5x18.58x0.15x25=1700KN

Weight of all beams= (5x24.5+6x18.5) x0.3x0.45x25=788KN

Weight of columns in first floor= 30x4.2x0.45x0.45x25=638KN

Weight of columns in other floors=30x4x0.45x0.45x25=607.5 KN

According to IS1893 Table (8) if the live load is more than 3KN/m^2 the 50% of it will be lumped on floors.

Live load in a typical floor=24.5x18.5x4x0.5=906.5KN
The live load at roof is taken zero.

Weight of brick infill at 1st floor= (5x24.5+6x18.5) x4.2x0.12x20=2354KN
Weight of brick infill in other floors= (5x24.5+6x18.5) x4x0.12x20=2242KN
Seismic weight calculation of the structure,
$W=W_1+W_2+W_3+W_4+W_5$
W_1, W_2, W_3, W_4 and W_5 these are the seismic weights in each floor respectively.

Table 3.4 Showing Seismic Weight calculation for 5 Story building

i	W_i (KN)	W_i (KN)
1	1700+788+638+906.5+2354	6386
2	1700+788+607.5+906.5+2242	6244
3	6244	6244
4	6244	6244
5	1700+788+(607.5/2)+(2242/2)	3913
$\sum$	29031 KN	

Seismic weight is found to be 29031KN

$V_B=\frac{ZI}{2R}\frac{Sa}{g}xW$

Z=024

I=1

R=5

Sa/g=2.5

$V_B=\frac{0.24x1}{2x5}x2.5W$=0.06W=0.06x29031=1742 KN

So the base shear for 5 story building is found to be 1742 KN.

Now the base shear is laterally distributed as per IS-1893-2002,

$Q_i = ((W_i h_i^2)/ (\sum W_i h_i^2))xV_B$

Table 3.5 showing the lateral distribution of base shear for G+4

i	Wi (KN)	h_i	$W_i h_i^2$ (KNm^2)	Q_i(KN)
1	6386	4.2	112649.04	33.98
2	6244	8.2	429394.64	129.57
3	6244	12.2	950492.24	286.75
4	6244	16.2	1675941.86	505.6
5	3913	20.2	2605743.44	786.1
$\sum$	29031		5774221.2	1742

So these lateral forces (Q_i) obtained are applied to the building laterally considering the center of mass and the response is obtained using pushover analysis.

Calculation of seismic forces for 12 story building

$W=W_1+10W_2+W_{12}$

Because the height of the first story columns differ that's why W_1 is not equal to W_2.

W_1=6386 KN

W_2=6244 KN

W_{12} =3913

So the seismic weight for 12 story building is found to be 72739 KN.

V_B =0.06W=0.06X72739= 4364 KN

So the base shear for 12 story building is found to be 4364 KN. Now the base shear is distributed laterally.

Now the base shear is laterally distributed as per IS-1893-2002,

$Q_i= ((W_ih_i^2)/ (\sum W_ih_i^2))xV_B$

V_B =4364 KN

Table 3.6 showing the lateral distribution of base shear for G+11

i	Wi (KN)	h_i	$W_ih_i^2$ (KNm^2)	Q_i(KN)
1	6386	4.2	112649.04	7.46
2	6244	8.2	429394.64	28.45
3	6244	12.2	950492.24	62.99
4	6244	16.2	1675941.86	111.07
5	6244	20.2	2605743.44	172.69
6	6244	24.2	3656736.16	242.34
7	6244	28.2	4965478.56	329.08
8	6244	32.2	6474028.96	429.057
9	6244	36.2	8182387.36	542.27
10	6244	40.2	10090553.76	668.73
11	6244	44.2	12198528.16	808.44
12	3913	48.2	14506310.56	961.38
$\sum$	72739		65848244.74	4364

Calculation of seismic forces for 22 story building

$W=W_1+20W_2+W_{22}$

W_1=6386 KN

W_2 =6244 KN

W_{22}= 3913 KN

So the seismic weight is calculated to be 135179 KN.

V_B=0.06W=0.06x135179=8111 KN

Now the base shear is laterally distributed as per IS-1893-2002,

Q_i= (($W_i h_i^2$)/ ($\sum W_i h_i^2$))xV_B

V_B =8111 KN

Table 3.7 showing the lateral distribution of base shear for G+21

i	Wi (KN)	h_i	$W_i h_i^2$ (KNm^2)	Q_i(KN)
1	6386	4.2	112649.04	2.39
2	6244	8.2	429394.64	9.12
3	6244	12.2	950492.24	20.19
4	6244	16.2	1675941.86	35.6
5	6244	20.2	2605743.44	55.357
6	6244	24.2	3656736.16	77.68
7	6244	28.2	4965478.56	105.48
8	6244	32.2	6474028.96	137.53
9	6244	36.2	8182387.36	173.82
10	6244	40.2	10090553.76	214.36
11	6244	44.2	12198528.16	259.15
12	6244	48.2	14506310.56	308.17
13	6244	52.2	17013900.96	361.45
14	6244	56.2	19721299.36	418.96
15	6244	60.2	22628505.76	480.72
16	6244	64.2	25735520.16	546.73
17	6244	68.2	29042342.56	616.98
18	6244	72.2	32548972.96	691.47
19	6244	76.2	36255411.36	770.22
20	6244	80.2	40161657.76	853.20
21	6244	84.2	44267712.16	940.43
22	3913	88.2	48573574.56	1031.9
$\sum$			381797142.3	8111

The Base Shear for 22 Story building is found to be 8111 KN, however this shear force was for the building with the section dimensions similar to 12 story building. After getting the results the ground floor columns were collapsed, therefore the section dimensions were modified and are given below.

Table 3.8 showing the modified section properties of 22 story building

Beam Size	600x800mm
Ground floor Columns	1000x1000mm
Other floors Columns	800x800mm

The seismic weight was found to be 190359 KN using STAAD Pro.

V_B=0.06W=0.06x190359=11421KN

The base shear for 22 story building was found to be 11421 KN and this base shear is laterally distributed using STAAD Pro. All the lateral forces for 5, 12 and 22 story buildings are respectively applied in pushover analysis while considering the center of mass. First fundamental mode shapes of the three buildings were also used in the pushover analysis, it was observed that the result for both laterally applied forces and mode shapes are same.

3.4 Loads on the structure

The structure is analyzed and designed for live load, seismic load as per IS-1893-2002 and dead load consisting of self-weight of beams, columns and slabs. The following figures show the different loads acting on the building.

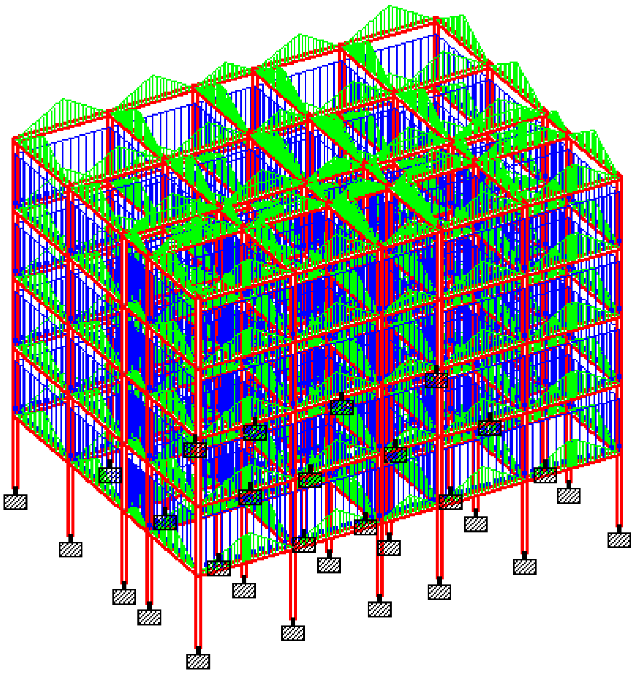


Figure 3.10 illustrating the brick infill load acting on the beams

Considering slab thickness 130mm floor load is calculated as below and Figure below shows the building with applied floor load

$0.13*25=3.25KN/m^2$

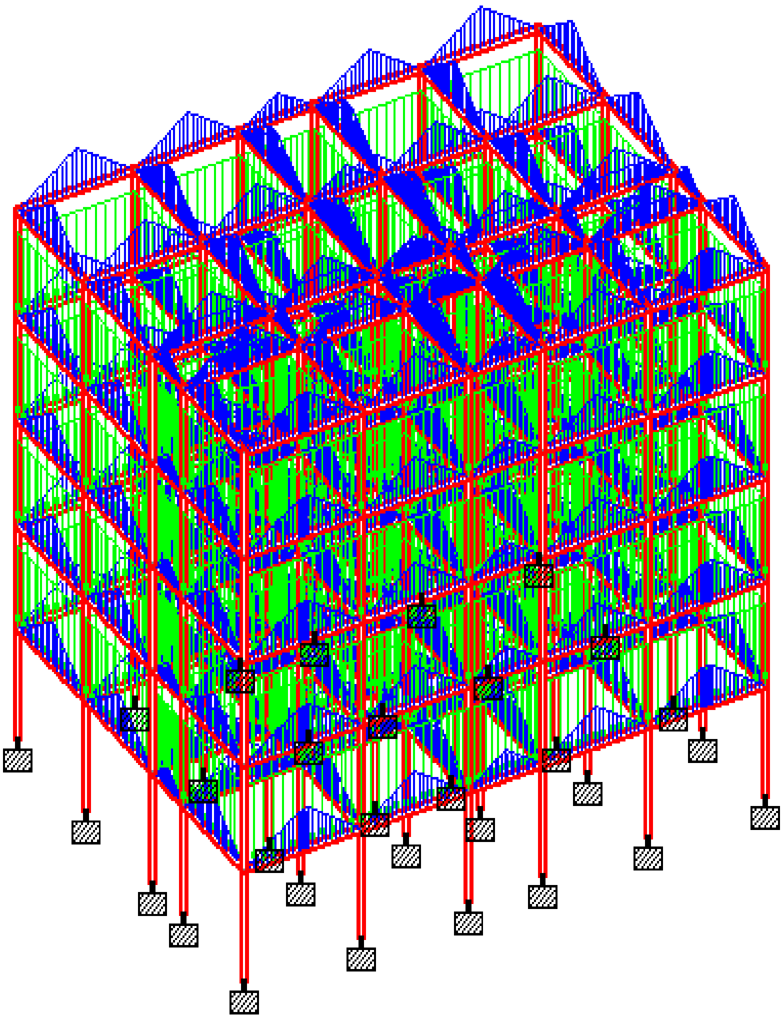


Figure 3.11 illustrating the floor load acting on the slabs

Live load was considered $3KN/m^2$ on the roof and $4KN/m^2$ for other floors the figures below show the live Load applied to the structure.

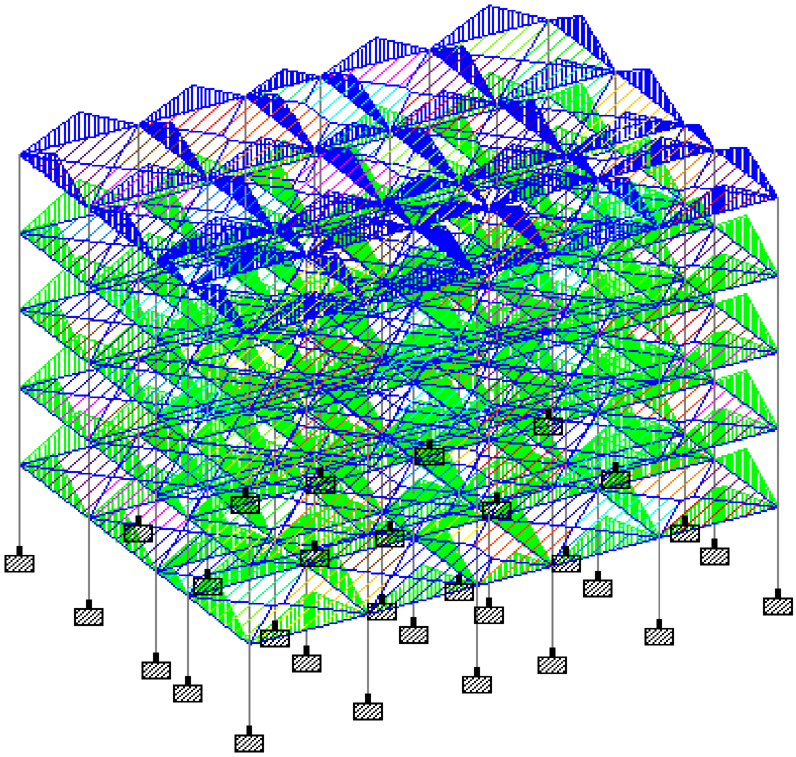


Figure 3.12 Illustrates the Live Load acting on the Roof

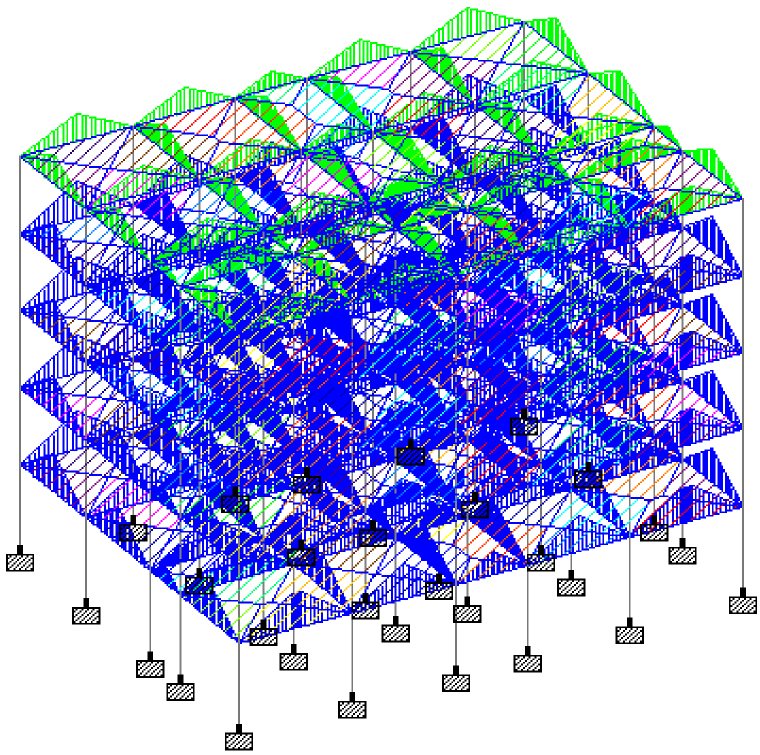


Figure 3.13 illustrates the live Load acting from 1st floor to the 4th

The following figures are taken from STAAD Pro after assigning section properties and loads:

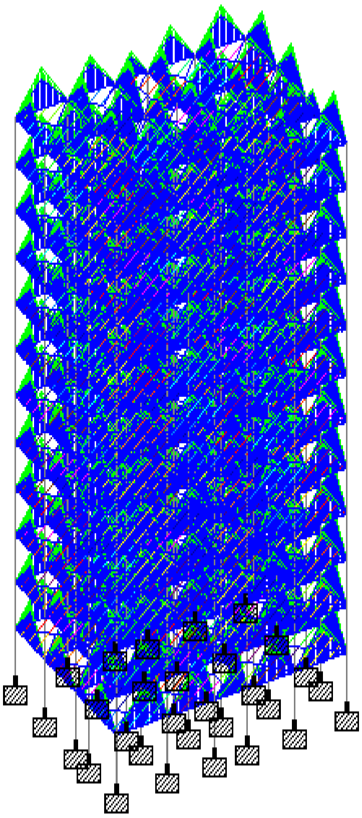


Figure 3.15 showing live load acting on 12 story building

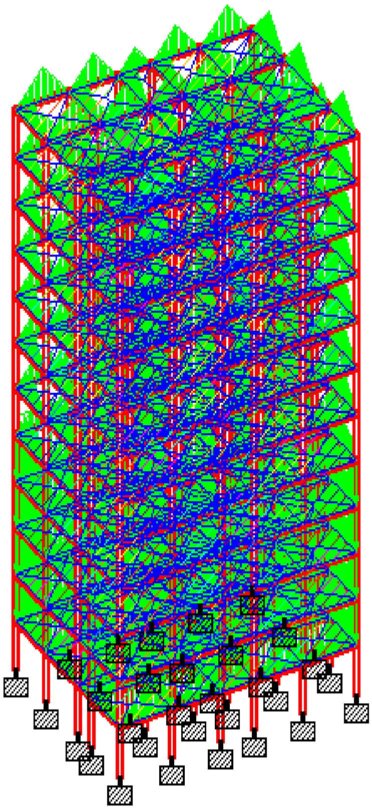


Figure 3.16 showing self-weight acting on 12 story building

The following figures are taken from STAAD Pro after assigning section properties and loads:

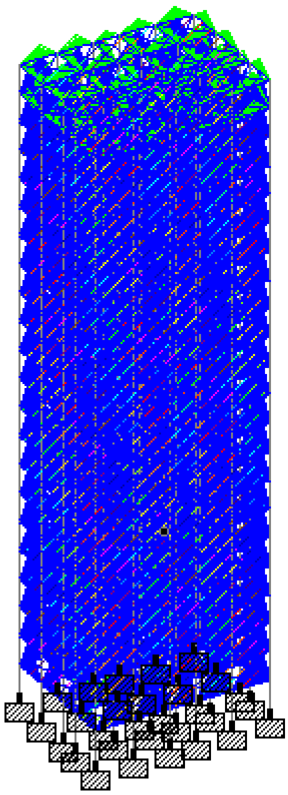


Figure 3.17 showing live load acting on 22 story building

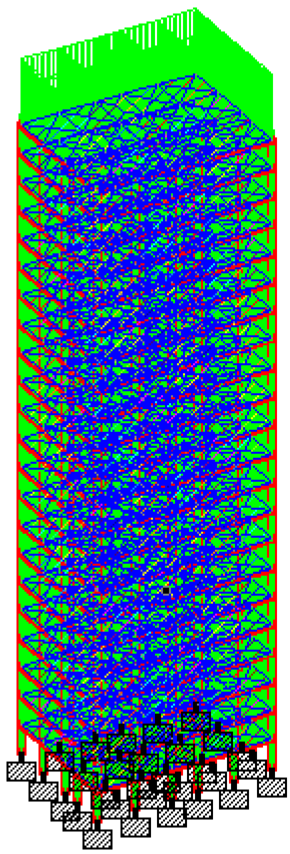


Figure 3.18 showing self-weight acting on 22 story building

CHAPTER 4 Reinforced Concrete Design

4.1 Introduction

This chapter covers the reinforced design of G+4, G+11 and G+21 Buildings using the design software STAAD Pro. The reinforcement details the beams and columns which developed the first hinges in the pushover analysis are given here for all three buildings.

4.2 Building Details

The 5, 12 and 22 story RC buildings which are located in Delhi fourth zone based on classification from IS1893-2002 is designed for gravity loads in STAAD Pro and hence the model was exported to SAP2000 to perform pushover analysis. The following details about reinforcement, shear and bending are obtained from STAAD Pro.

4.3 RC Design of G+4 Building

The details of 5 story building is given below:

Beams=300mmx450mm

Columns= 450mmx450mm

Concrete Grade= M30

Steel Grade=Fe415 HYSD bar

The Following 3D model is taken from STAAD Pro. , after assigning dimensions of beams and columns.

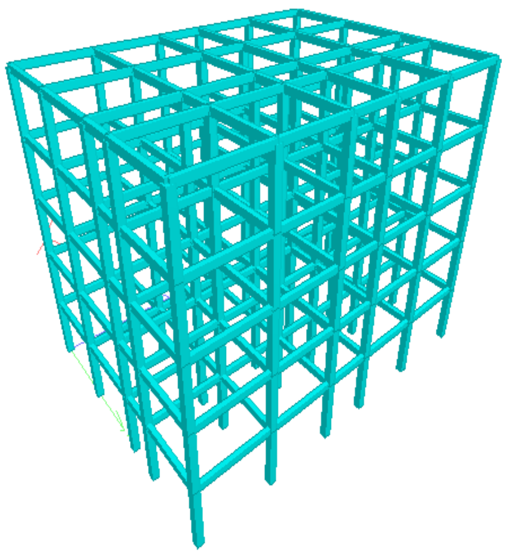


Figure 4.1 showing the 3D model of the building

Detailing of beams

Rectangular beams of dimension 450mmx300mm is provided, the following figure shows reinforcement detailing of a beam as a sample. M Grade concrete and Fe415 Grade steel was used for the RCC Design.

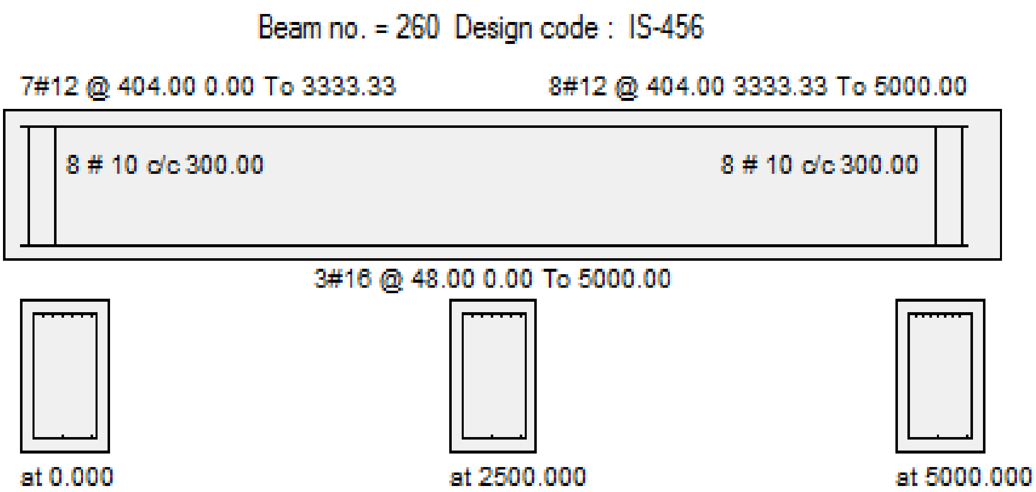
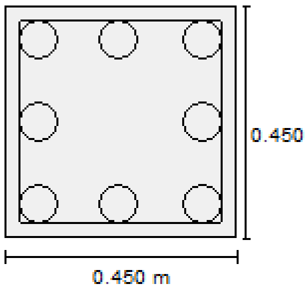


Figure 4.2 showing the reinforcement detailing of beam of G+4

Detailing of columns

Rectangular columns of dimension 450mmx450mm are provided with M30 grade concrete and Fe415 grade of steel. The following figure shows the reinforcement details taken from STAAD Pro.



Design Load

Load	3
Location	End 1
Pu(Kns)	923.25
Mz(Kns-Mt)	64.44
My(Kns-Mt)	52.77

Design Parameter

Fy(Mpa)	415
Fc(Mpa)	25
As Reqd(mm²)	662
As (%)	0.44
Bar Size	12
Bar No	8

Figure 4.3 showing the reinforcement detailing of column of G+4

4.4 RC Design of G+11 Building

The STAAD Pro Model of G+11 is given below,

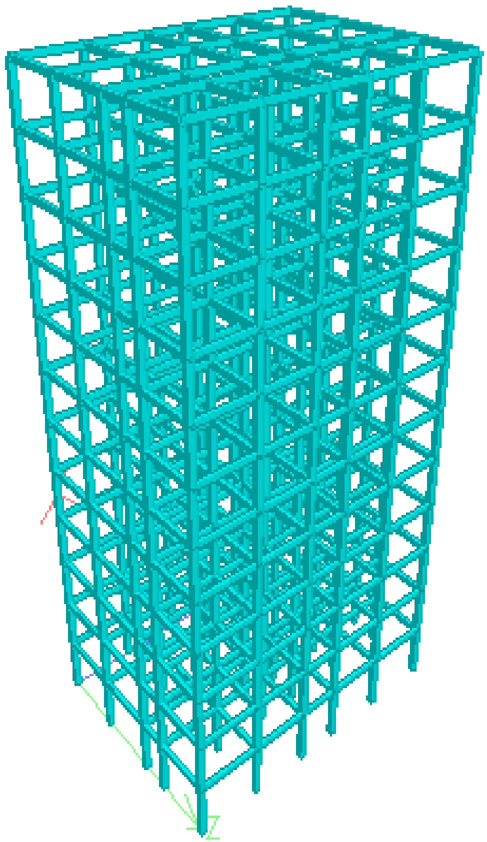
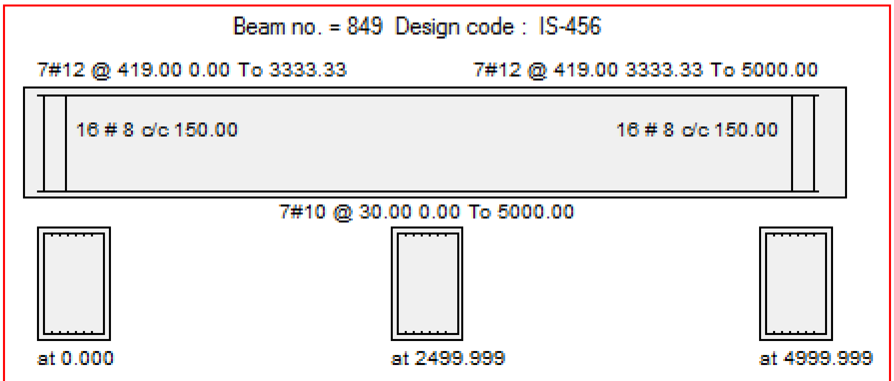


Figure 4.4 Showing the STAAD pro Model of G+11

Detailing of beams

Rectangular beams of dimension 450mmx300mm is provided, the following figure shows reinforcement detailing of a beam as a sample. M30 Grade concrete and Fe415 Grade steel was used for the RCC Design.

The following figure showing the reinforcement in a beam which developed the first plastic in G+11 Building.



Mz Kn Met	Dist. Met	Load
72.33	2.5	3
-104.09	0	3
-105.28	5	3

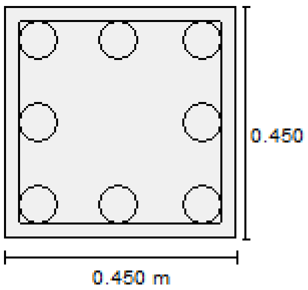
Fy(Mpa)	415
Fc(Mpa)	30
Depth(m)	0.449999988
Width(m)	0.300000011
Length(m)	5

Figure 4.5 showing the reinforcement detailing of beam of G+11

Detailing of columns

Rectangular columns of dimension 450mmx450mm are provided with M30 grade concrete and Fe415 grade of steel. The following figure shows the reinforcement details taken from STAAD Pro.

The following figure shows the column reinforcement for G+11 Building, this column developed the first plastic hinge.



Design Load

Load	3
Location	End 1
Pu(Kns)	2668.07
Mz(Kns-Mt)	27.62
My(Kns-Mt)	21.78

Design Parameter

Fy(Mpa)	415
Fc(Mpa)	30
As Reqd(mm²)	1595
As (%)	0.79
Bar Size	16
Bar No	8

Figure 4.6 showing the reinforcement detailing of column of G+11

4.5 RC Design of G+21 Building

The STAAD Pro model of G+21 is given below,

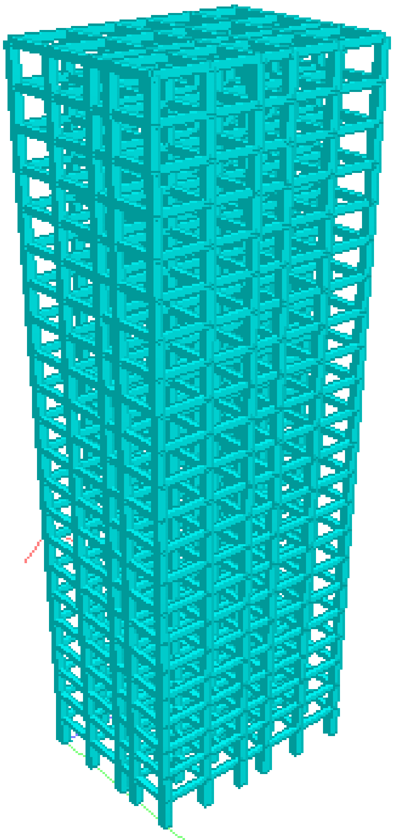


Figure 4.7 Showing the STAAD Pro Model of G+21

Detailing of beams

Rectangular beams of dimension 80mmx600mm is provided, the following figure shows reinforcement detailing of a beam as a sample. M30 Grade concrete and Fe415 Grade steel was used for the RCC Design.

The following figure showing the reinforcement in a beam which developed the first plastic in G+21 Building.

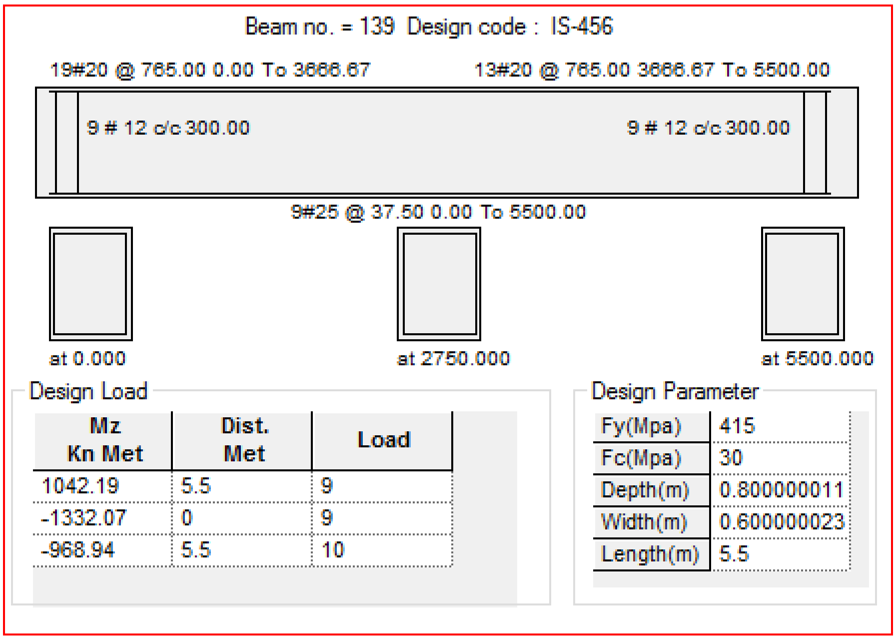


Figure 4.8 showing the reinforcement detailing of beam of G+21

Detailing of columns

Rectangular columns of dimension 800mmx800mm are provided with M30 grade concrete and Fe415 grade of steel. The following figure shows the reinforcement details taken from STAAD Pro.

The following figure shows the column reinforcement for G+22 Building, this column developed the first plastic hinge.

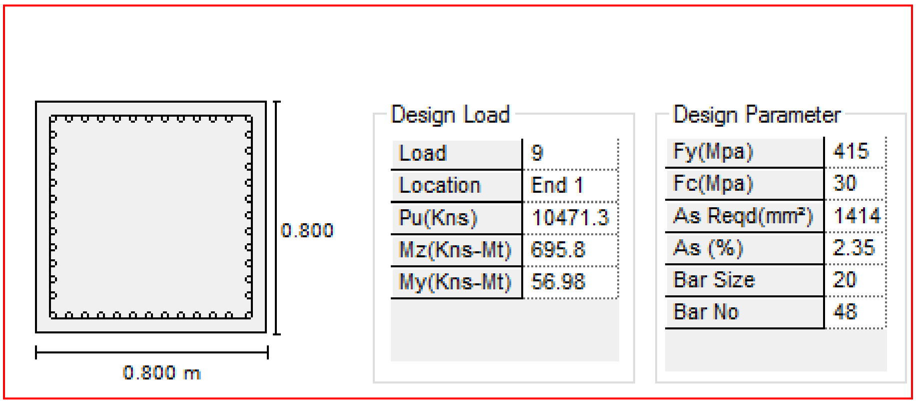


Figure 4.9 showing the reinforcement detailing of column of G+21

NOTE:

While performing the pushover analysis in SAP2000 it was observed that depending on the default reinforcements of design software may lead to underestimation of base shear and will ultimately result in bad performance, its therefore encouraged to do the manual calculation for the reinforcements using the moments and shear force developed in the columns and beams of the concerned buildings.

CHAPTER 5

5.1 Performance based Evaluation

The most rational method to use in defining the displacement based response of the structure where the behavior of the building will nonlinear, is the pushover analysis methodology which is broadly used in the present time. It is capable of providing the most accurate estimate of the capacity of the structure. However the dynamic time history analysis results may be more accurate. In performing this analysis the loads are monotonically applied to the structure in an increased manner statically. These lateral loads will result in the formation of plastic hinges at very critical sections of the structure which will lead to the redistribution of the forces and step by step the failure mechanism will be appeared. In this process, it is possible to achieve the non-linear relationship between the lateral force applied and the deformation of the structure which is monitored at a specific location, usually expressed in the form of the capacity curve that is the plot between the base reactions versus roof displacement.

The pushover curve is the plot of base shear vs displacement it shows the capacity of the building it should be noted that the design base shear which is calculated using the procedure given in the IS 1893 should always be less than that obtained in the pushover curve.

Basically the pushover curve is the capacity curve which shows the capacity of the building that how much load the structure can take before it reaches the failure mechanism.

In terms of performances there are various levels of performances, it should be chosen based on the economic conditions and the sensitivity of the structure. The higher the performance the higher will be the cost of the construction. The European code FEMA 356 recommends that the basic performance objectives are:

1. Life safety under Design Basis Earthquake (DBE)
2. Collapse prevention under Maximum Considered Earthquake (MCE)

The general Performance objectives are discussed:

Selection of a building performance level under a selected earthquake level is based on economic decisions, available expertise, and inconvenience during intervention.

I. Single level Performance objective

One combination of performance level and earthquake level.

II. Dual level Performance objective

Two combinations of performance levels and earthquake levels.

Performance objectives can be divided into three parts:

I. Basic safety objective (BSO)
   i. Life safety under DBE
   ii. Collapse Prevention under MCE

II. Enhanced Performance objective (Higher level than BSO)

III. Reduced Performance objective (Lower level than BSO)

Please note that in India the collapse prevention is generally considered the target performance under MCE however. It is a partial performance objective as per FEMA 356

Force based design vs performance based design:

FORCE-BASED DESIGN

I. Determine the gravity loads and lateral loads.
II. The members are assumed to be elastic.
III. Find the moments, shear and axial forces.
IV. Size the component ensuring (Force Demand ≤ Capacity)
V. Check deflections, crack-widths of beams and drift of building.

PERFORMANCE-BASED ANALYSIS

Based on quantifying the deformation of members and the structure as a whole

I. This is an extension of limit states method of analysis.
II. Performance levels are analogous to the limit states.
III. Performance levels are indicators of states of damage.
IV. Performance-based analysis is used in seismic retrofit when it comes to take decisions.

5.2 Background

Nonlinear static analysis, or pushover analysis is developed in the past twenty years where now it has become the widely used method for performance based design. It is having a simple methodology and can record the response of multi degree of systems in very less amount of time and it considers the plastic behavior of the structure. This method includes certain assumptions which are approximate and simplified because of those assumptions some extent of change in the prediction of seismic demand can be expected.
However nonlinear static analysis is very efficient and accurate in determining the response of the structure under seismic loads. This can be said compare to force method. As we can get more accurate result than the pushover analysis by using dynamic time history analysis. Very rarely the reliability of the pushover analysis in calculating the global seismic response of structures have been a matter of discussion. In this regard many enhanced procedures for pushover analysis have been suggested to overcome the limitations of traditional pushover method.

5.3 Pushover Analysis Procedure

Pushover analysis includes the application of increasing lateral loads or deformations to a nonlinear mathematical model of a structure. The nonlinear load-deformation behavior of each section of the structure is modelled in separate way. In a force-controlled push, the loads are applied monotonically until either the total load reaches a target value or the building has a collapse mechanism. In a displacement-controlled push, the displacements are increased monotonically until either the displacement of a predefined control node in the building exceeds a target value or the building has a collapse mechanism. For convenience, the control node can be taken at the design center of mass of the roof of the building. The target displacement is the maximum considered displacement that is approximated and predefined initially.

First of all the structure to be designed for gravity loads in any design software and then the pushover analysis to be performed. The lateral load as per is 1893 is applied in increasing manner or the first fundamental mode shape is used to take the seismic demand force from the dynamic characteristics. It is very important to determine the displacement control point and the direction of the first fundamental mode. The plastic hinges to be defined for each beam and column at both ends. There are two possibilities the first possibility is that the load may reach its target value and the building at that value of load is safe, where the second case it can reach collapse mechanism. Even in the collapse mechanism the hinges should be carefully studied and the performance point maybe observed if the performance point exists and the failure at that level is acceptable then the overall performance of the structure at that level is acceptable.

Capacity: The capacity of the structure in general depends on the displacement each individual member can take or we can say that the capacity of structure depends on the capacities of individual components deformation. Considering this phenomenon the critical sections are determined and the mathematical model of the structure is enhanced and the response is calculated again until the demand is satisfied.

Demand: As we know the earthquake yields in complex horizontal displacements for any structure. The maximum target displacement is the displacement assumed to be from the potential earthquake. Basically this target displacement is the demand. Once the maximum forces applied to the building laterally could not result in the displacement beyond the target displacement then it is concluded that the building performed well.

Performance Level: The Performance level of the building is defined in terms of the collapse state of the building. Buildings which yields to more plastic hinges is said to have performed badly against certain earthquake. When there are less number of plastic hinges then it’s said to be performing well.

Chapter 6 The Pushover Analysis results

6.1 Introduction

Pushover Analysis was carried out over the designed 5, 12 and 22 story buildings respectively using SAP 2000(V16). The members were assigned with their self-weight of the building considering beams, columns slabs and as well as brick infill. And the analysis was carried out for combinations of loads as per IS 1893-2002. The building is pushed in lateral directions until the collapse mechanism is reached. The various curves resulting from the analysis are briefly discussed below.

6.2 The Pushover analysis of G+4 RC Building

The following figure shows the Pushover curve base shear vs lateral displacement.

The unit for Base Reaction is KN and Displacement is meter. The maximum node displacement is equal to 0.230m. The Pushover Curve shows that the building has objectively high Base Shear Capacity than the Design Base Shear.

The Design base shear (V_B) was found to be 1742 in chapter 3 and the capacity is 2900KN which is much higher, hence the building is safe for this level of earthquake.

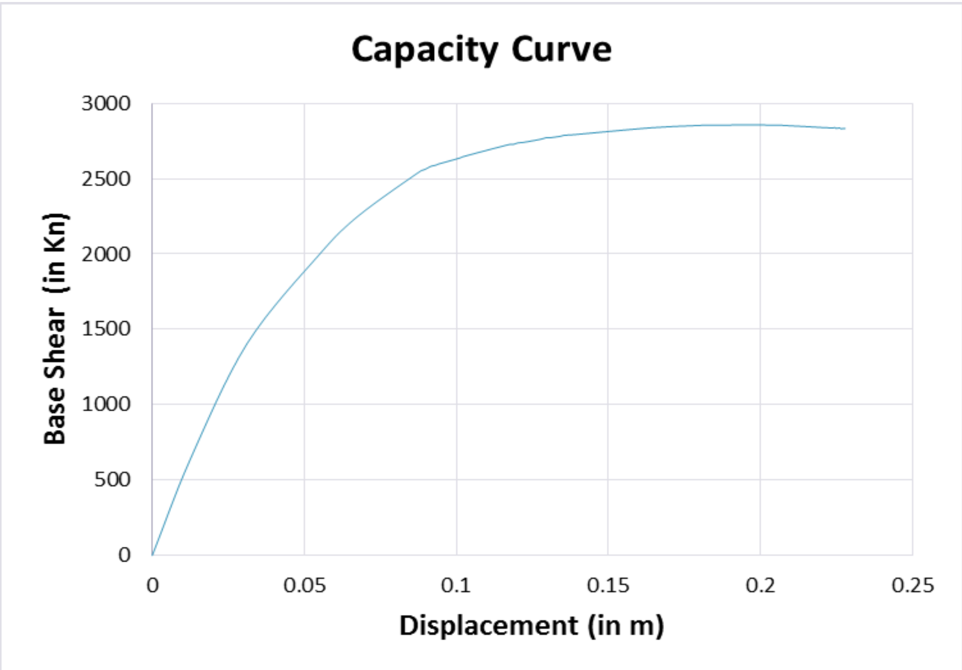


Figure 6.1 shows the pushover curve

The following Figure shows the formation of hinges in a 3D model of the building.

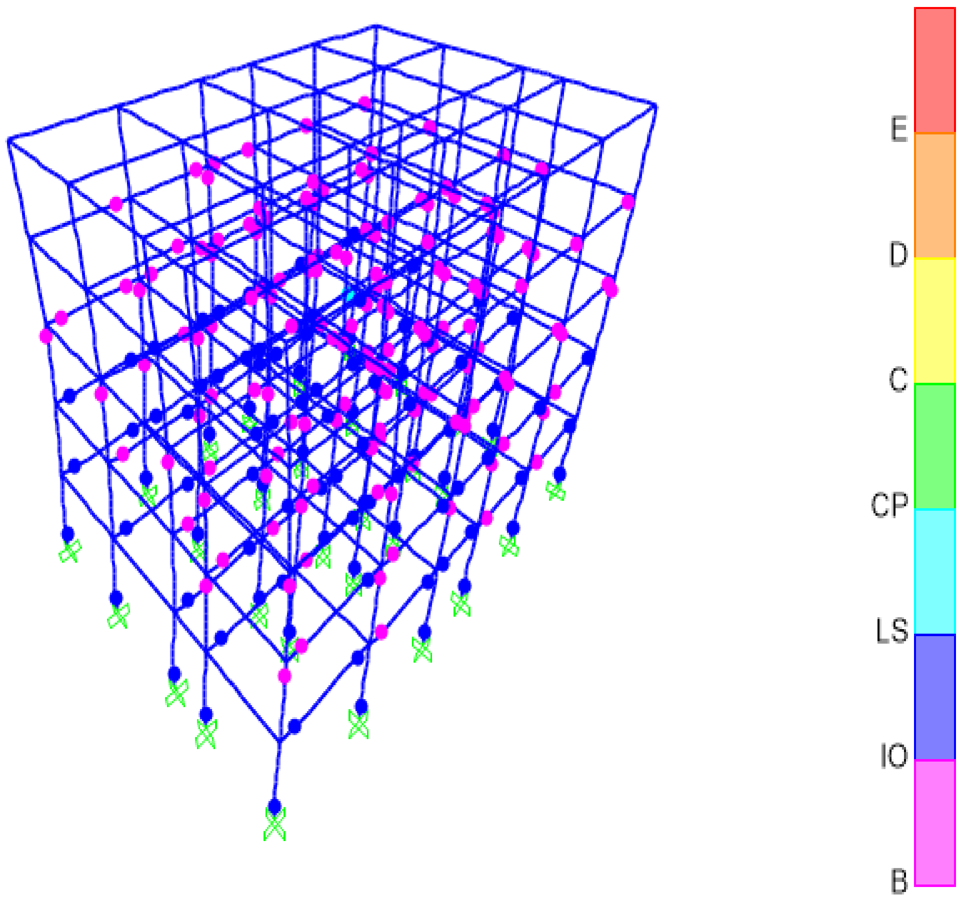


Figure 6.2 showing formation of hinges in 3D form

The following Figure 5.3 shows the formation of hinges in X-Z plane

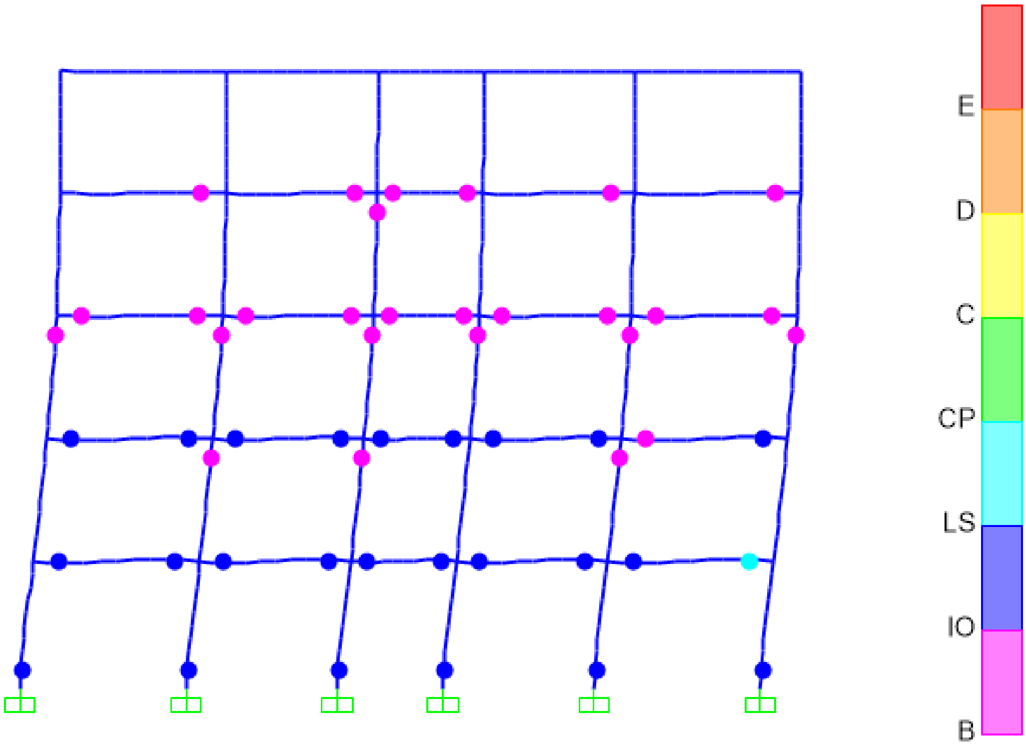


Figure 6.3 showing the formation of hinges in X-Z plane

Capacity Spectrum, Demand Spectrum and Performance Point:

The capacity curve is also called as pushover curve which is a plot of base shear vs displacement where the capacity spectrum is the plot between base acceleration and the roof displacement. Where the instantaneous spectral acceleration and displacement point or demand point is called the demand spectrum. The demand spectrum leads to the nonlinear behavior of the building. And the intersection of capacity curve and demand curve is called the performance point.

The Performance point is the intersection of the demand and capacity curves.
During pushover analysis if a building is having performance point and the damage at the same point is acceptable then the structure is said to be satisfying the target performance level.

The following figure shows the performance point, the intersection of demand and capacity curve. Spectral Acceleration (Sa) vs Spectral displacement (Sd)

Table 6.1 the conclusion from Performance point of G+4

Base shear(KN)	2679.179	Roof displacement (m)	0.108
Spectral Acceleration, Sa (m/s)	0.488	Spectral displacement, Sd (m)	0.082
Effective time period, Teff (s)	0.823	Effective damping, βeff	0.189

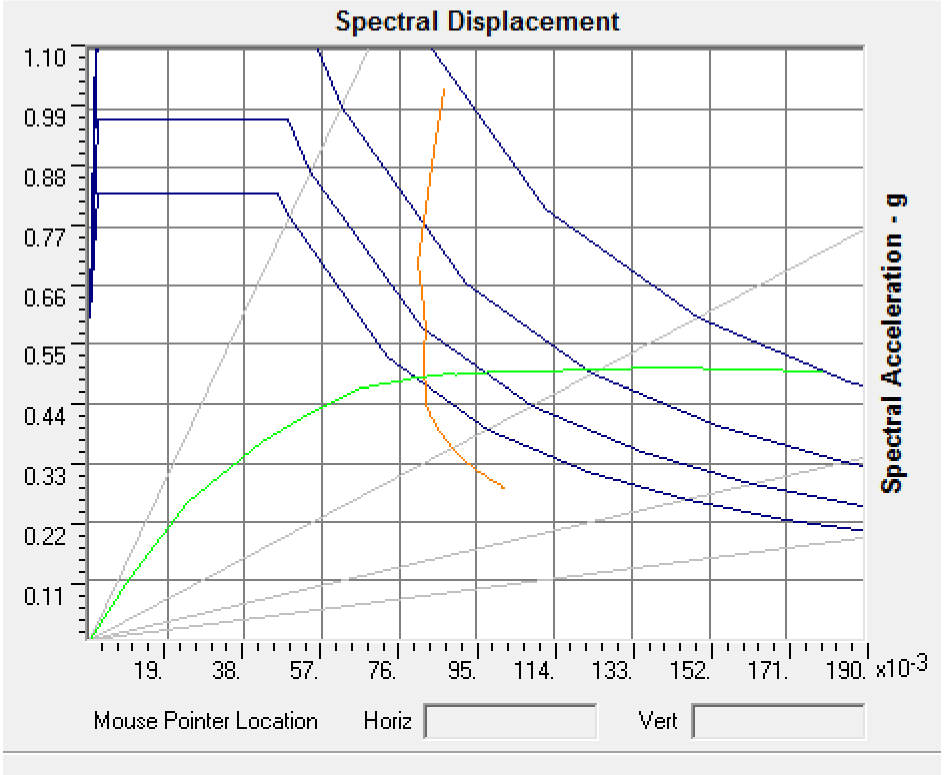


Figure 6.4 showing the performance point

6.3 The Pushover analysis of G+11 RC Building

The following figure shows the Pushover curve base shear vs lateral displacement.

The unit for Base Reaction is KN and Displacement is meter. The maximum node displacement is equal to 0.43m. The Pushover Curve shows that the building has objectively high Base Shear Capacity than the Design Base Shear.

V_B was found to be 4364KN and the capacity from the plot is 4800KN which is higher, hence the performance of the building for this level earthquake is acceptable.

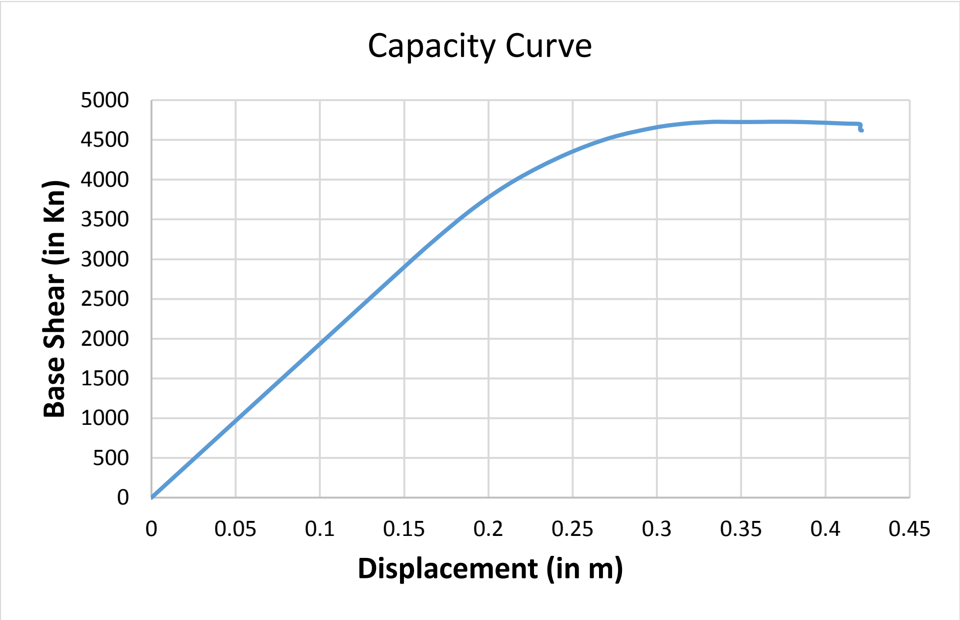


Figure 6.5 Pushover curve (base shear vs displacement) for 12 Story Building

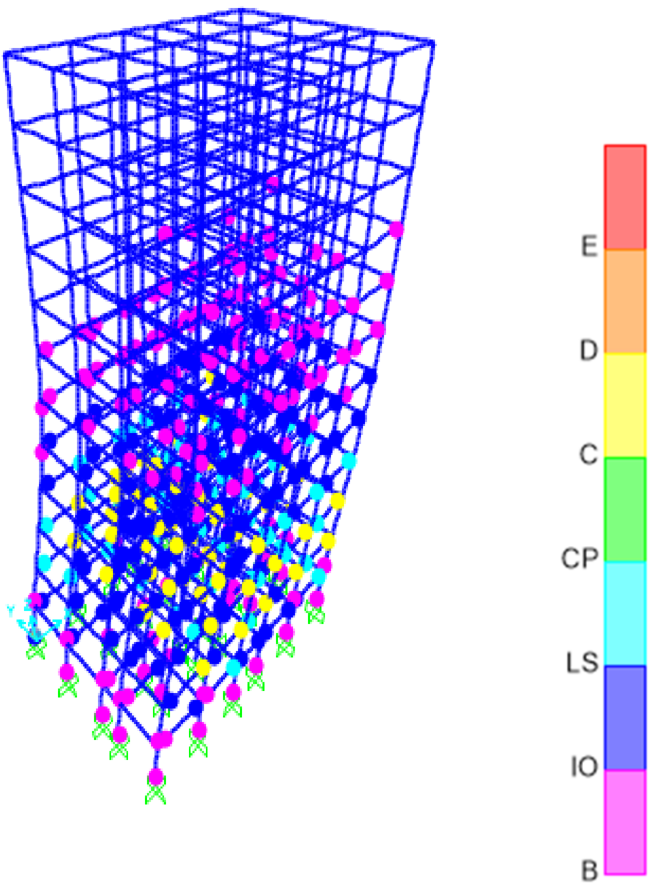


Figure 6.6 Formation of plastic hinges in SAP2000

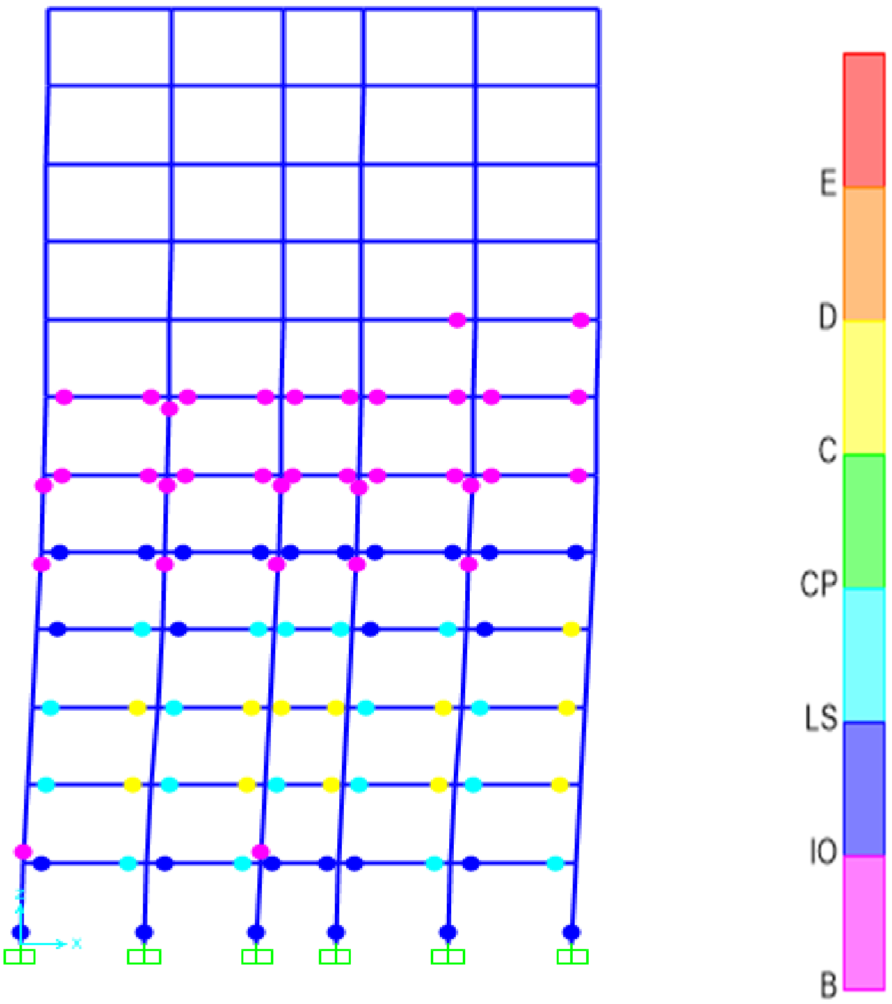


Figure 6.7 above shows the formation of plastic hinges in X-Z plane.

The Performance point is the intersection of the demand and capacity curves. During pushover analysis if a building is having performance point and the damage at the same point is acceptable then the structure is said to be satisfying the target performance level.

The following figure shows the performance point, the intersection of demand and capacity curve. Spectral Acceleration (Sa) vs Spectral displacement (Sd)

Table 6.2 the conclusion from Performance point of G+11

Base shear(KN)	4415.444	Roof displacement (m)	0.166
Spectral Acceleration, Sa (m/s)	0.140	Spectral displacement, Sd (m)	0.137
Effective time period, Teff (s)	1.986	Effective damping, βeff	0.170

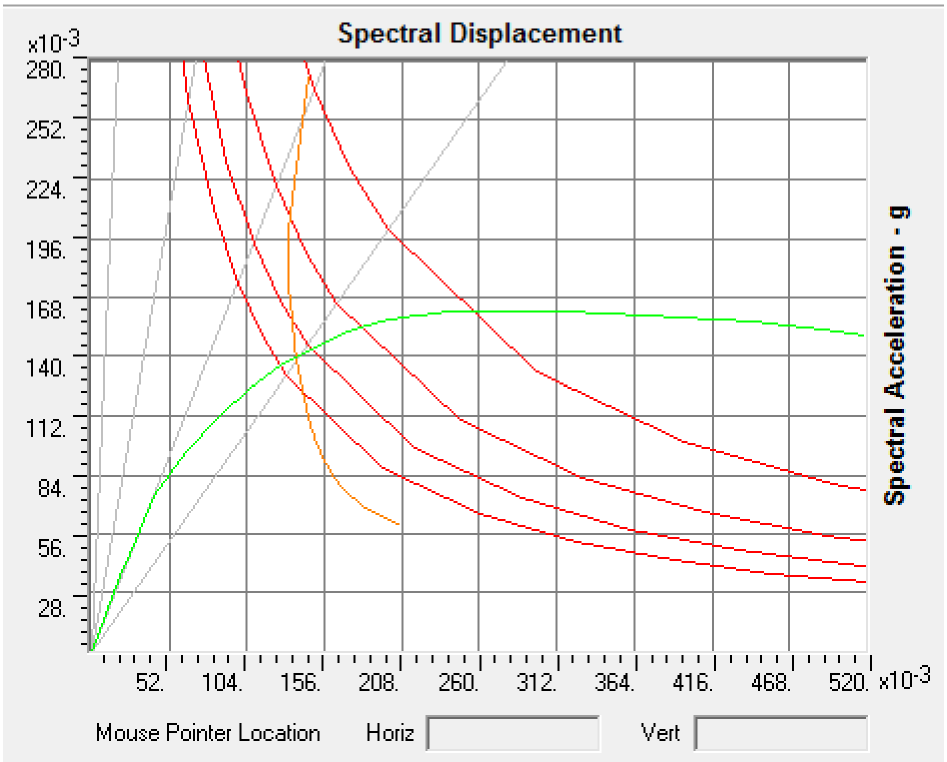


Figure 6.8 showing intersection of Demand and capacity curve (Performance point)

6.4 The Pushover analysis of G+21 RC Building

The following figure shows the Pushover curve base shear vs lateral displacement.
The unit for Base Reaction is KN and Displacement is meter. The maximum node displacement is equal to 0.67m. The Pushover Curve shows that the building has objectively high Base Shear Capacity than the Design Base Shear.
V_B was found to be 11421KN and the capacity from the plot is 12382KN which is higher, hence the performance of the building for this level earthquake is acceptable.

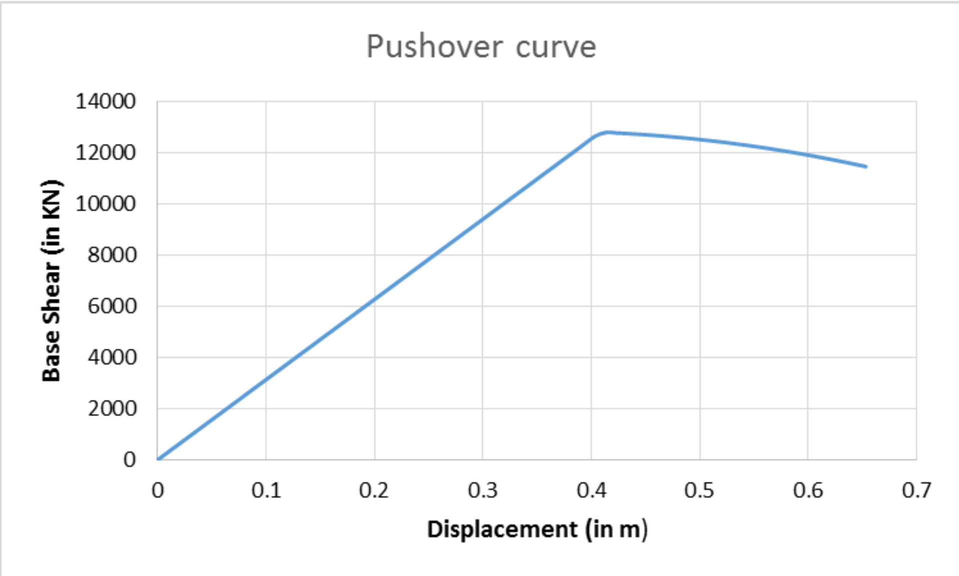


Figure 6.9 Pushover curve (base shear vs displacement) for 22 Story Building

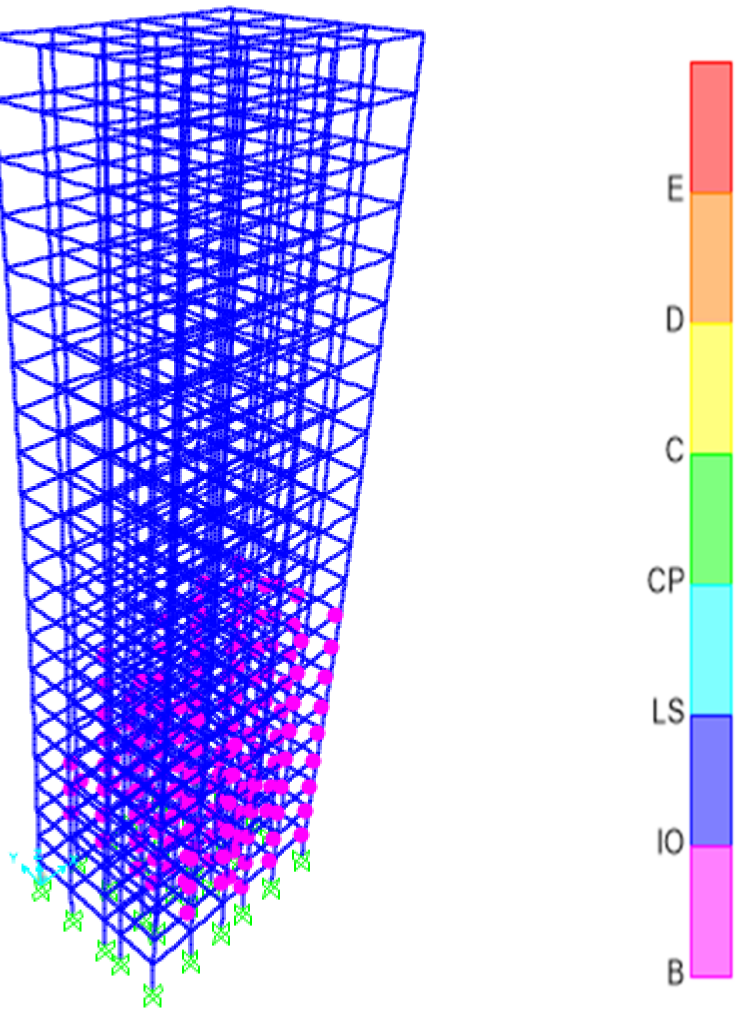


Figure 6.10 showing Formation of Plastic hinges in SAP2000 for 21 Story Building

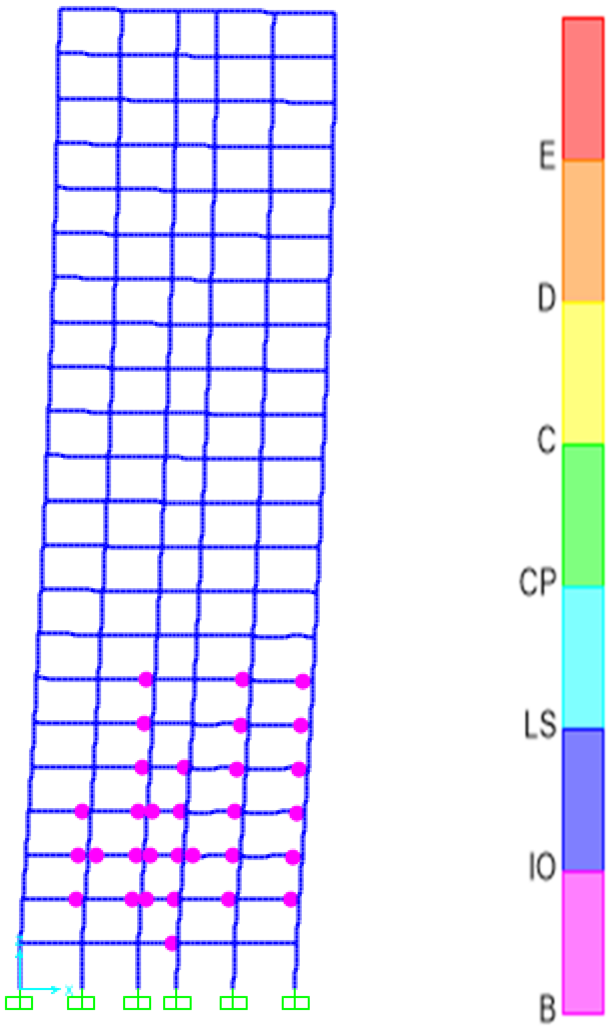


Figure 6.11 shows the formation of plastic hinges in X-Z plane for 21 story building

The Performance point is the intersection of the demand and capacity curves.
During pushover analysis if a building is having performance point and the damage at the same point is acceptable then the structure is said to be satisfying the target performance level.

The following figure shows the performance point, the intersection of demand and capacity curve. Spectral Acceleration (Sa) vs Spectral displacement (Sd)

Table 6.3 the conclusion from Performance point of G+21

Base shear(KN)	12021.25	Roof displacement (m)	0.381
Spectral Acceleration, Sa (m/s)	0.138	Spectral displacement, Sd (m)	0.236
Effective time period, Teff (s)	2.131	Effective damping, βeff	0.168

6.5 Comparing the Results

The following Table shows the comparison of Design base shear and capacity of building at the performance point, it clearly indicates that the capacity of all three RC Buildings G+4, G+11 and G+21 are higher than the design base shear. Hence the performance at this point is acceptable.

Table 6.4 Showing the comparison of capacity and design base shear of three buildings

	G+4 RC Building	G+11 RC Building	G+21 RC Building
Design Base Shear (V_B)	1742 KN	4364 KN	11421 KN
Capacity of Performance Point	2679.179 KN	4415.44 KN	12021.25

7. SUMMARY AND CONCLUSION

7.1 Summary

In the present study 5, 12 and 22 buildings are designed as per Indian standard IS 456:2000 the main objective of the study was to get the desired performance level for the building according to Indian standard codes. The building was designed in STAAD Pro. Initially and then it was exported to SAP2000 for performing non-linear static analysis, default plastic hinges property was assigned to the beams and columns at both ends as per FEMA 356. FEMA356 recommends M3 (flexural moment) hinges for beams and P-M2-M3 (Axial force with biaxial moment) hinges for columns. Hence the building was pushed from +x direction after determining the control node. And finally the model was analyzed and results were carried out.

The main objective of performance based Design is to ensure life safety under Design Basis Earthquake (DBE) and Collapse prevention under Maximum Considered Earthquake (MCE). In this study these objectives were achieved.

7.2 CONCLUSION

After studying all the curves and tables we came to the following conclusion that the Pushover Analysis result shows that the Building was able to achieve the performance point within its elastic range.

Further we can conclude that:

. **1.** Pushover analysis the simplest way to get the response of existing or new structures.

2. Considering three different RC building it was concluded if the buildings are designed with proper sections and reinforcement details as per standard codes will perform better under seismic forces.

4. The performance of the pushover analysis mostly depends on the material used in the structure

8. FUTURE SCOPE OF STUDY

Non-linear time history analysis can be used for the structure to have a more accurate Results of the structure's capacity and understanding a more realistic demand scenario.

The pushover analysis can be done in varies ways like considering the dynamic characteristics of the structure. The static load or the base shear distributed in the lateral direction and the inverted triangular load method. To confirm whether all gives the same result one can conduct all three and compare the results. In the current study consideration of modes shapes as well as the lateral forces are applied and it was observed that both gives the same result.

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